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THE SPECIFIC HEAT OF AMMONIA.

By Henry A. Babcock.

Investigations on Light and Heat made and published with aid from the Rumford Fund.

(*Continued from page 3 of cover.*)

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Presented by Henry Crew. Received Dec. 1, 1919.

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I. Introduction.

The investigation described in this paper and carried on in the Laboratory of Physics of Northwestern University during the years 1914–15–16, is a continuation of measurements on the thermodynamic properties of ammonia, (NH_3), made in the Research Laboratory of Physical Chemistry of the Massachusetts Institute of Technology in 1912–13.

The work at the Massachusetts Institute of Technology was divided into two parts: the equation of state for ammonia was determined by Keyes and Brownlee,[1] while Keyes and the writer made measurements of the specific heat. The mean specific heat capacity of liquid ammonia was determined by a parallel method of mixtures, using water as a reference substance, between $0° - 20°$ C. and between $20° - 50°$ C.[2] Realizing the unsuitability of this method for higher temperatures, where the specific heat varies rapidly with temperature, Keyes devised a "point" method which gave the mean specific heat over very small temperature ranges.[3] By this method some rough measurements were made between $25° - 95°$ C., but the data was not considered of sufficient accuracy to warrant publication.

The investigation described in this paper is an elaboration of this latter method.

II. Experimental Method.

The specific heat capacity at constant volume, of a mixture of ammonia, liquid and vapor, (NH_3), has been determined over a temperature range from 30° to 125° C., by an absolute method, which consists of heating the ammonia, by measured amounts of electrical energy, through temperature ranges of about 1° C., from various initial temperatures.

The calorimeter contains the calorimetric fluid, a heater, a thermometer, and a sealed tube enclosing the ammonia. When the calorimeter has been brought to some initial temperature, a measured

1 "Thermodynamic Properties of Ammonia," Keyes and Brownlee. John Wiley and Sons. (1916). Also Frederick G. Keyes, Amer. Soc. of Refrig. Eng. Jour., **1**, 9 (1914).

2 Keyes and Babcock, Amer. Chem. Soc. Jour., p. 1524, 39², (1917).

3 "Thermodynamic Properties of Ammonia," Keyes and Brownlee. John Wiley and Sons. (1916), p. 29.

amount of current is passed through the heater for a certain time, and the change of temperature of the calorimeter observed. The mean heat capacity of the entire apparatus over this temperature interval is obtained by dividing the energy input by the temperature change produced by this energy. Since the rate of change of heat capacity does not vary appreciably during a heating of one degree, the value obtained is taken as the heat capacity at the mean temperature of the experiment. A series of such measurements are made at various temperatures, and the heat capacity, denoted by $\left(\frac{\delta H_1}{\delta \theta}\right)$, is plotted as a function of the temperature.

To correct for the heat capacity of the system exclusive of the ammonia, the liquid container is emptied, and the series of measurements repeated. The heat capacity of the empty apparatus,[4] denoted by $\left(\frac{\delta H_2}{\delta \theta}\right)$, is plotted as a function of the temperature, and this curve constitutes a calibration of the calorimeter. The trend of these $\frac{\delta H}{\delta \theta}$

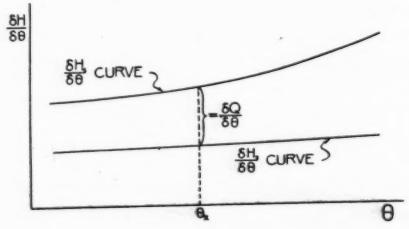


FIGURE 1.

curves is shown in Figure 1. At any temperature θ_x, the heat capacity of the ammonia is measured by the difference of the ordinates to the two curves, and this difference is denoted by $\frac{\delta Q}{\delta \theta}$.

To obtain the *specific* heat capacity of the ammonia, it is necessary to divide the values of $\frac{\delta Q}{\delta \theta}$, at each temperature by the mass, M, of ammonia in the container. The volume of this container is sensibly

4 The correction for the heat capacity of the air in the container is negligible.

constant, so that the specific heat so obtained is at constant volume.[5] This specific heat is denoted by $c_{v_{12}}$. The subscript $_v$ signifying "at constant volume," and the subscripts $_1$ and $_2$, denoting "of a mixture of liquid and vapor," subscript $_1$ referring to the vapor phase and subscript $_2$ to the liquid phase. To be exact, it is necessary to specify the numerical value of the particular specific volume at which the measurements were made. We have then

$$c_{v_{12}} = \frac{1}{M}\frac{\delta Q}{\delta \theta} \tag{1}$$

and for the laboratory equation

$$c_{v_{12}} = \frac{1}{M}\left(\frac{\delta H_1}{\delta \theta} - \frac{\delta H_2}{\delta \theta}\right) \tag{2}$$

in which the terms in the brackets are functions of the temperature, θ. Equation 2 gives the specific heat at any temperature θ, in terms of

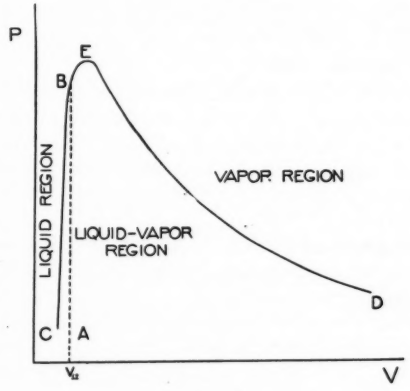


FIGURE 2.

the mass of ammonia and the heat capacities of the apparatus full and empty, measured at the same temperature θ. The methods of measuring δH_1, δH_2, $\delta\theta$, and M, will be described in detail hereafter.

Given values of $c_{v_{12}}$ as a function of the temperature θ, at some

5 Measurements were made to determine the temperature dilatation of the container, and this quantity was found to be negligible.

specific volume v, it is possible to *calculate* the values of the saturation specific heats of both the liquid and the vapor, over the same temperature range, provided certain thermodynamic quantities for the substance in question are known. This computation will be given later.

Drawing the pressure-volume diagram for a substance, in the neighborhood of the liquid-vapor region, it is possible to indicate graphically the path over which the heating takes place, during a determination of $c_{v_{12}}$. This path is shown by AB in Figure 2. The saturation specific heat of the liquid is the specific heat determined by heating along the liquid line CE; and the saturation specific heat of the vapor is that determined by heating along the vapor line DE.

The measurements described in this paper yield the specific heat along the line AB.

III. Apparatus. Specifications.

1. **Calorimeter.** Figure 3.

   a. Calorimeter Tube.
   Material steel; inside diameter 62 mm.; wall thickness 1 mm.; length 270 mm. Supported by steel pins from asbestos board cover 7 mm. thick. All metal projections from calorimeter through cover capped with asbestos board.

   b. Calorimetric Fluid.
   5153 grams of mercury. Advantages: low vapor pressure, negligible vaporization, low heat capacity per unit volume, high heat conductivity.

   c. Liquid Container. Calorimeter Stirring.
   Constructed from seamless steel tube, outside diameter, 46 mm., wall thickness, 4 mm., length 250 mm. Designed to withstand critical pressure of liquid ammonia: 112.3 atmos. Hexagon nut milled on each end of barrel. Hexagon caps screwed on both ends. Gaskets, thin sheet copper. Joints and barrel tested to 135 atmos. Filling plug screwed into upper cap. Hemispherical joint, set up dry. Six 1.6 mm., stirring fins milled lengthwise of barrel. Container mounted in bearings in calorimeter. Oscillated by stirring shaft and gearing, driven by small motor. Geared to rotate three turns in each direction.

Voltage drop across the armature was kept constant during a measurement by a sliding rheostat. Four bladed copper churn mounted in bearings inside of container to stir ammonia and distribute heat by conduction. Stirring shaft insulated from calorimeter by asbestos board plug. Upward thrust on stirring shaft taken by ball socket thrust bearing at upper end of shaft.

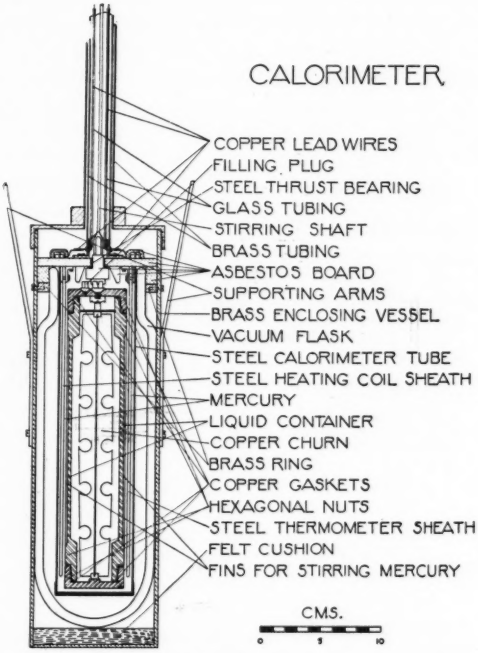


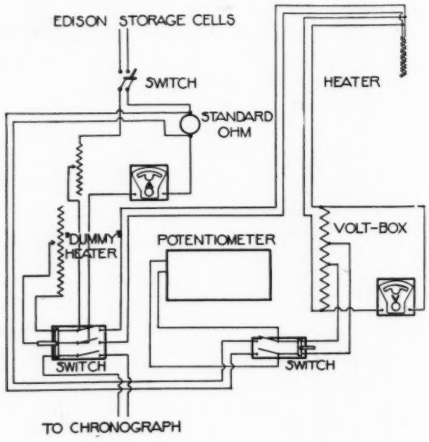
FIGURE 3.

d. Heating Coil.

Manganin resistance coil, built into calorimeter. Enclosed in flattened steel sheath, 3 mm. thick, 8 mm. wide, and 240 mm. long. Heater introduced heat equally at all levels. Supported from asbestos board cover by steel brackets. Described more fully below.

e. Thermometer.
Platinum resistance thermometer, built into calorimeter. Enclosed in flattened steel sheath, similar to heating coil sheath. Extended entire length of calorimeter tube. Averaged differences of temperature at different levels.

f. Vacuum Jacket.
Wide mouthed [6] Dewar flask, enclosing calorimeter tube. Top closed by asbestos board calorimeter cover supported on asbestos board ring carried by enclosing vessel.



POTENTIOMETER CIRCUITS

FIGURE 4.

g. Enclosing Vessel.
Brass cylinder fitted with screwed-on cover, totally immersed in constant temperature oil bath. Cover threads packed with red lead mixed with machine oil. Cover provided with brass tube conveying leads and stirring shaft from the calorimeter to the outside. Leads were insulated by small glass tubes fixed inside the brass tube.

[6] There is no particular advantage in this contracted neck shown on the Dewar flask. This bottle was at hand, so the rest of the apparatus was built to fit it.

2. **Energy Measuring Apparatus.**

a. Circuits. Figure 4.
Arranged to measure current through heating coil, and voltage drop across heating coil, alternately, by potentiometer method. The "dummy" heater, equal in resistance to the heating coil, keeps the line hot and the batteries at the desired voltage while the heater switch is off.

b. Heating Coil.
Resistance 12.2 ohms. Manganin wire, laced vertically on thin baked mica strip,[7] enclosed by two baked mica cover strips. Manganin wire used on account of its zero temperature coefficient resulting in no initial excess of current when the heater switch is thrown on. Heating coil enclosed in flattened steel sheath supported in calorimeter.

c. Potentiometer and Galvanometer.
Wolff high resistance dial type potentiometer.
Leeds and Northrup type HN moving coil galvanometer.

d. Batteries.
Twenty type B6H, 112.5 amp. hr. Edison Cells, used solely for supplying energy to the calorimeter.

e. Standard Cell.
Weston Cadmium Cell, certified by the Bureau of Standards.

f. Standard Resistance.
1 ohm. N. B. S. Standard Resistance furnished and certified by Leeds and Northrup.

g. Chronograph.
Ordinary pen and drum type, regulated by laboratory clock. Connected to heater switch in such manner as to record automatically length of time heating current was on.

3. **Thermometric Apparatus.**

a. Standard Thermometer.
Four lead compensated Callendar open coil type.[8] 2 meters of 0.1 mm. diameter platinum wire wound on

---

7 The vertical lacing was found to be an easy way to overcome the tendency of the stiff manganin wire to twist the delicate mica supporting frame when wound on in the ordinary manner. Holes were punched in the frame with a needle at proper intervals and the wire threaded through these holes.

8 "Measurement of High Temperatures," Burgess and Le Chatelier. John Wiley and Sons. (1912), p. 202.

dehydrated mica frame enclosed in glass tube. Leads of 0.3 mm. platinum wire arc welded to coil terminals. Leads to switch, # 20 B & S guage copper wire arc welded to platinum leads and soldered to switch terminals. Resistance at 0°C. 25.87 ohms. Used for calibrating observing thermometer by comparison, and for measuring temperature of oil bath.

b. Observing Thermometer.
Four lead compensated Dickinson & Mueller flat coil type[9] of special construction. 2 meters of 0.1 mm. platinum wire wound on flat mica strip dehydrated by baking in electric furnace at 900° C. Enclosed in flat steel sheath and built into calorimeter. No drying agent was used. Top sealed with china cement. Leads of # 20 B.&S. gauge copper wire, arc welded to coil terminals and soldered to switch terminals. Resistance at 0° C. 25.68 ohms. Used for measuring temperature change in calorimeter.

c. Wheatstone Bridge. Figure 5.
This bridge is a modification of one designed by the Bureau of Standards and built by the Leed's and Northrup Co.,[10] Range of Bureau of Standards instrument is 0° — 115° C. Range of special bridge used in these measurements, 0° — 450° C.
The instrument differs from the Bureau of Standards design in three particulars:

1. It is provided with 9, 11, 7, and 12 ohm extension coils to increase the range of the instrument.
2. A mercury cup contact link is inserted on the thermometer side of the bridge to compensate the resistance of the mercury cup link used to connect in the extension coils.
3. Thirteen instead of ten of the one ohm coils are used.

The extension coils cannot be adjusted to the same accuracy as the 1 ohm coils when the bridge is built, but their value may be determined in terms of the resistance of the slide wire of the bridge, and within the limits of accuracy of the bridge itself by the expedient of making a double setting with a resistance thermometer at a constant temperature and therefore at a constant resistance. With the ther-

9 Dickinson and Mueller, Bull. Bur. of Standards, **3** (1907), p. 641.
10 Leeds and Northrup Bulletin, no. 806.

mometer in a steam hypsometer, a bridge reading may be made with the link in the 25 ohm position, and then by shifting the link to the 34 ohm position and moving the plug in the one ohm bank back 9 steps, and again balancing with the slide wire, a second reading is obtained which is equal to the first, which gives an equation determining the

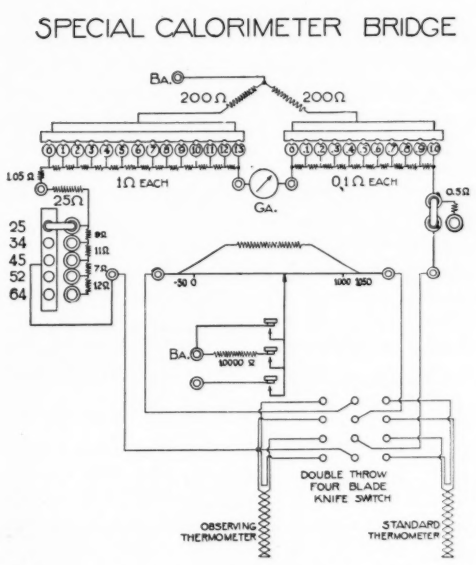


FIGURE 5

unknown value of the nominally 9 ohm coil. The bridge is designed for use with thermometers having a resistance at 0° C. of 25.3 ohms and a fundamental interval of about 10.0 ohms. By double settings at the steam point (100°), the napthalene point (218°), the benzophenone point (306°), and the sulphur point (445.7°), the four extension coils may be accurately determined. A thermometer may be calibrated and the extension coils measured at the same time.

The measuring current used with this bridge was about 0.004 amperes.

d. Thermometer Switch.
Double throw, four blade, all copper knife switch especially constructed. Used to connect either of the two thermometers to the bridge. Later work showed that mercury cup links are more satisfactory for this purpose.

e. Galvanometer.
High sensitivity, Leeds and Northrup, D'Arsonval instrument,[11] type b: resistance 12 ohms; period 5 secs., sensi-

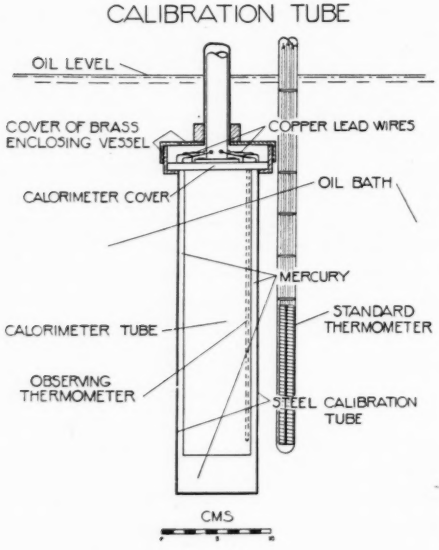


FIGURE 6.

tivity 5 mm. per micro-volt at a scale distance of 1 meter. Supported on brick wall. Scale observed by telescope at distance of 2.4 meters. Scale divisions were arbitrary but so spaced that a movement of the bridge wire equivalent to 0.00001 ohm produced a deflection of approximately $\frac{1}{10}$ of a scale division. A change in resistance of 0.00001 ohm was equivalent to about 0.0001° C. on the standard thermometer.

11 Leeds and Northrup Bulletin, no. 228.

f. Apparatus for calibration of Standard Thermometer. Instrument was calibrated at the ice, steam, and naphthalene points. Shaved ice and distilled water mixed to a slush and contained in a thermos bottle were used for the zero point. A steam hypsometer with three outlets and a manometer was used for the steam point. The head of the thermometer was protected from radiation by a square flat tin shield between the head and the hypsometer. A special glass tube with two side condensing tubes was used for the napthalene boiling apparatus. Instrument protected by the usual aluminum radiation and splash shield, and the head protected as in the determination of the steam point.

g. Apparatus for calibration of Observing Thermometer. Assembled calorimeter withdrawn from the vacuum flask and its enclosing brass cylinder, and screwed into the "calibration tube" shown in Figure 6. This calibration tube was filled with mercury. The whole apparatus was then immersed in the oil bath, the observing thermometer being in metallic contact with the oil through the medium of the two tubes of mercury. Comparisons with the standard thermometer were made at three temperatures.

4. **Constant Temperature Bath.**

a. Tank.
Cubical galvanized iron tank, 2 feet on a side, riveted and soldered at the bottom and lagged with felt. Cover of ½-inch asbestos board with central opening to admit the calorimeter which was supported by arms from this cover. Tank was mounted on castors to facilitate movement in case of emergency.

b. Oil.
Steam engine cylinder oil was used for the bath but owing to its viscosity at low temperatures it is not a particularly desirable substance.

c. Stirring.
Bath was stirred by eight 9-inch propeller blades carried on two vertical shafts, driven by belt from direct current motor whose speed could be controlled by a rheostat.

d. Adjusting heater.
3600 watt heater, wound with nichrome tape on asbestos

paper on steel tubes. Used only for changing the bath temperature from one fixed point to another.

e. Main Heater.
Wound with nichrome wire on asbestos paper on wood. Adjustable by means of external rheostats. Maximum power 550 watts. Used to maintain bath temperature at any desired point. Set so as to just allow the bath to cool.

f. Regulating Heater.
Wound with nichrome wire on asbestos paper on steel tube. Adjustable by means of external rheostats. Maximum power 50 watts. Switched on and off by an automatic relay switch.

g. Temperature Regulator.
U tube of glass 3 cm. in diameter containing 500 cc. of mercury. Stop-cock and reservoir at top of one limb, for coarse adjustment. 1 mm. diameter capillary and reservoir at top of other limb. Contact needle of steel, with well rounded blunt point. Screw adjustment on needle for fine setting.

h. Cooling Coils.
Thirty feet of $\frac{1}{2}$-inch copper pipe coiled in the bottom of tank and connected to the water mains. Needle valve for adjustment. Used for regulation of temperatures below 35° C. and for rapid cooling of the bath from high temperatures.

i. Removable Cover.
Cover arranged to be lifted by means of block and tackle, carrying with it propellers, heating coils, temperature regulator, and calorimeter. This was useful when it was necessary to make repairs.

IV. Laboratory Equations and Methods of Measurement.

1. Laboratory Equation for Specific Heat at Constant Volume of a Mixture of Liquid and Vapor.

This equation, previously given, is

$$c_{v_{12}} = \frac{1}{M}\left(\frac{\delta H_1}{\delta\theta} - \frac{\delta H_2}{\delta\theta}\right) \qquad (2)$$

The volume denoted by v_{12}, is the specific volume of the mixture of liquid and vapor, and is given by the relation

$$v = \frac{V}{M} \tag{3}$$

where V = total inside volume of container, and M = total mass of ammonia. Usually we shall write, simply, v with the subscripts $_1$ and $_2$ omitted but understood. However, whenever it is desired to designate the particular specific volume at which these measurements were made, we shall write $v_{2\cdot6593}$, where 2.6593 is understood to be in ccs./gram.

2. **Laboratory Equation for Energy Input to Calorimeter.**

During the time that the heating current is on, alternate readings are made of the voltage drop across the smaller coil of the volt box and of the voltage drop across the standard 1 ohm resistance in series with the heating coil. Between each pair of readings, the e. m. f. of the potentiometer batteries was balanced against that of the standard cell.

For any one measurement, the current through the heating coil is given by

$$\mathrm{I} = \frac{\text{average voltage drop across standard ohm}}{\text{resistance of standard ohm at the observed temperature}} \tag{4}$$

and the voltage drop across the heater, is given by,

E = average voltage drop across smaller coil of volt box x ratio of volt box coils (5)

and the energy input to the calorimeter is given by

$$\delta H = EI\,(t_2 - t_1) \tag{6}$$

$(t_2 - t_1)$ being the interval of time during which the heating current is on.

To distinguish between ammonia and calibration measurements, the subscripts $_1$ and $_2$ are used, thus δH_1 = the energy input for an ammonia measurement, δH_2 = the energy input for a calibration measurement. The temperature of the standard ohm was read at the beginning and end of each measurement and the average of these two readings used to compute the resistance required for Equation 4. The temperature of the standard cell was also read at the beginning and end of each measurement.

3. Ratio of Volt Box Coils.

The ratio of the volt box coils, as determined, included the resistance of the lead wires. The average of ten readings was taken to allow for a slightly varying current.

4. Laboratory Equation for the Calorimeter Temperature Change: Cooling Correction.

The temperature change occurring in the calorimeter and measured by the observing thermometer, is not the temperature change actually produced by the introduction of the heat δH_1 or δH_2, but is complicated by several circumstances which must be allowed for in computing the true $\delta\theta$. These circumstances are as follows:

1. The temperature of the mercury in the calorimeter rises more rapidly than that of the container and ammonia, so that the temperature recorded on the thermometer at any instant, while very closely the temperature of the *mercury*, is not the equalized temperature of the *calorimeter*.

2. A heat transfer to the surroundings takes place due to the difference of temperature between the mercury and these surroundings.

3. Heat is added to the mercury and the calorimeter by the friction of stirring.

The method of procedure in correcting for these effects was as follows:

The oil bath was set to regulate at the temperature at which it was desired to make a measurement, and the calorimeter temperature brought to within a degree or so of this bath temperature. No attempt was made to have the calorimeter temperature always bear the same relation to the bath temperature, as it was desired to see how closely the method of computing these temperature data eliminated such variables. The theory takes account of these differences of calorimeter and bath temperature and if the conditions are always the same, the agreement between results is rather a check on the reproducibility of the apparatus than a true indication of the experimental error. A half hour was allowed to elapse before measurements were begun, to permit time for the parts of the calorimeter to equalize their temperature differences. Figure 7 is a typical time-temperature calorimetric curve, and shows the effects described below. Stirring was started and readings made of the temperature at intervals of one minute.[12] It was assumed that the small amount of heat intro-

[12] The readings were made almost exactly on the even minute. To accomplish this, the galvanometer telescope was focused on a watch hung on the

duced by stirring did not sensibly raise the temperature of the mercury above that of the container and the ammonia. This is, of course, not strictly true. Readings were continued for ten minutes before the heating current was applied, the changes of temperature during this period being due to heat transfer to the surroundings and to the heat of stirring. Exactly at the end of the tenth minute the heater switch

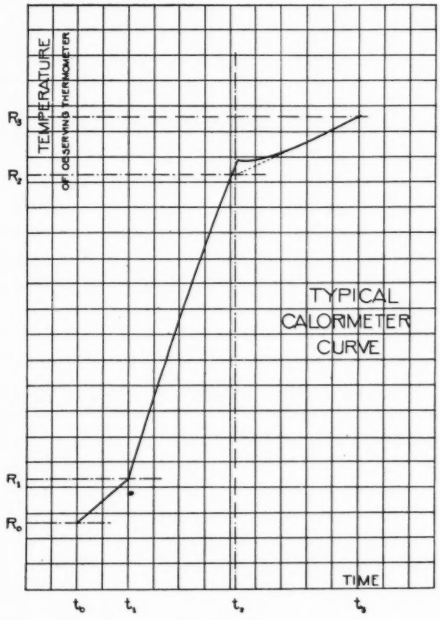


FIGURE 7.

was closed and measurements of the energy input begun by an assistant. The temperature of the mercury now began to rise rapidly, and its value was recorded at intervals of one minute. When the container was loaded with ammonia, this heating was continued for

scale, and so arranged that the cross hair coincided with the center of the second hand. The bridge was kept in balance by changing the slide wire and at the instant the second hand came to the 60 second mark, the movement of the slide wire was stopped and the reading recorded.

twenty minutes, and when the container was empty, for fifteen minutes. At the end of this time the heater was cut off. The temperature of the mercury continued to rise for about twelve seconds and then started to drop. This "coast" of the mercury temperature is due, no doubt, to the lack of equalization of temperature between the thermometer on one side of the calorimeter, and the heater on the other side. The heater is the hottest part of the calorimetric system while the current is on, and some time is required to allow the heat to flow around to the thermometer after the current is shut off. In other words, the temperatures recorded on the thermometer during the heating period are not exactly mercury temperatures, but are slightly below the true equalized mercury temperature. However, the amount of this lag is so small that no correction was made for it.

The drop of temperature occurring after this "coast" takes place, is, however, far from negligible, and is very noticeable. This drop is explained by the fact that the container and its contents are lagging behind the mercury during the heating period, so that after the heater is cut off, the mercury is losing heat both to the surroundings and to the container, which accounts for the rapid drop in its temperature. As the temperature differences between container and mercury get less and less, the curve drops less steeply, and after a time, a point is reached where the curve becomes sensibly a straight line, or at most a line with very slight curvature. Where this occurs, it is assumed that the calorimeter has equalized its temperature differences and that the curve of temperature against time from that point on is due entirely to stirring and heat transfer to the surroundings, as during the initial period. This point of equalization may be located fairly accurately by plotting the curvature, $(d^2\theta/dt^2)$, as a function of the time. After the point of equalization is passed, the curvature is practically zero, while before this it is changing very rapidly. While the slope of the curvature function has no actual discontinuity, a "corner" may be determined with some degree of certainty. The final line may slope either up or down depending on the difference of temperature between bath and calorimeter, and no attempt was made to have this slope the same in each observation. This final line became sensibly straight after about ten minutes in the case of the ammonia measurements, and after about fifteen minutes in the case of the calibration measurements. *This straight line is projected back to the time ordinate corresponding to the instant at which the heater was cut off, and the value of the temperature so obtained is taken to be the equalized temperature of the calorimeter at the instant the switch was cut off.*

The initial value of the equalized temperature is known by the intersection of the initial line with the time ordinate through the point where the heater was switched on, and the above procedure gives the final value; the difference of the two is the "observed temperature change." It remains to correct this observed temperature change for the heat transfer to the surroundings and for the heat due to stirring, during the time of the heating period. Two assumptions are made:

1. That the rate at which the mercury changes temperature due to heat transfer to the surroundings is proportional to the temperature difference. (Newton's Law of Cooling.) This may be written

$$d\theta_r/dt = K\,(\theta_a - \theta)$$

$d\theta_r$ being a change of temperature due to heat transfer alone, K, the modulus of thermal leakage, assumed constant for any one measurement, θ_a, the temperature of the surroundings, assumed constant for any one measurement, and θ, the actual temperature at any instant of the mercury.

2. That the rate of temperature change due to stirring is constant throughout any one measurement. This may be expressed

$$d\theta_s/dt = \lambda = \text{a constant.}$$

where $d\theta_s$ is a change of temperature due to stirring alone.

Since all temperature measurements are made in terms of resistance instead of in degrees, it is convenient to rewrite these two equations in terms of R rather than θ.

$$dR_r/dt = k\,(R_a - R) \tag{7}$$

$$dR_s/dt = \lambda, \text{ a constant.} \tag{8}$$

R being the resistance corresponding to the temperature of the mercury at any instant. The sum of these two rates, given by (7) and (8), $\left(\frac{dR_r}{dt} + \frac{dR_s}{dt}\right)$, represents the rate at which the temperature is changing due to heat transfer and stirring alone. Calling this sum, $\left(\frac{dR_c}{dt}\right)$, we have

$$\left(\frac{dR_c}{dt}\right) = (kR_a + \lambda) - kR \tag{9}$$

which is the differential equation of both the initial and final lines, and moreover gives the "cooling rate" during the heating period. This equation may be integrated to give the "cooling correction." To ob-

tain the value of the constant quantity $k\,(R_a + \lambda)$, we make use of the fact that the initial and final lines are sensibly straight, which amounts to saying that the change in R of Equation 9 for short intervals of time, is not enough to change the slope, $\frac{dR_c}{dt}$. Giving R its mean value for the initial line which is, $\frac{R_1 + R_0}{2}$, where R_0 is the first point on that line and R_1 the last, Equation 9 becomes

$$\frac{dR_c}{dt} = \frac{R_1 - R_0}{t_1 - t_0} = (kR_a + \lambda) - \frac{k}{2}(R_1 + R_0) \tag{10}$$

and giving R its mean value for the final line, $\frac{R_3 + R_2}{2}$, where R_2 is the value of the resistance obtained by projecting back the final line to the time ordinate through the point at which the heater was cut off, and R_3 is the last point on the final line, Equation 9 becomes

$$\frac{dR_c}{dt} = \frac{R_3 - R_2}{t_3 - t_2} = (kR_a + \lambda) - \frac{k}{2}(R_3 + R_2) \tag{11}$$

(10) gives us the value of $(kR_a + \lambda)$ and eliminating $(kR_a + \lambda)$ between (10) and (11) gives us the value of k, as follows

$$(kR_a + \lambda) = \frac{R_1 - R_0}{t_1 - t_0} + \frac{k}{2}(R_1 + R_0) \tag{12}$$

$$\frac{k}{2} = \frac{\dfrac{R_1 - R_0}{t_1 - t_0} - \dfrac{R_3 - R_2}{t_3 - t_2}}{(R_3 + R_2) - (R_1 + R_0)} \tag{13}$$

Integrating equation (9) from t_1 to t_2 to obtain the cooling correction to be applied to the observed temperature change, and substituting (12) in the expression,

$$\int_{t_1}^{t_2} \frac{dR_c}{dt}\,dt = \frac{R_1 - R_0}{t_1 - t_0}(t_2 - t_1) + \frac{k}{2}(R_1 + R_0)(t_2 - t_1) - k\int_{t_1}^{t_2} R dt \tag{14}$$

The mean value of R between R_1 and R_2 may be called R_m so

$$\int_{t_1}^{t_2} R dt = R_m (t_2 - t_1) \tag{15}$$

and substituting this in (14)

$$\int_{t_1}^{t_2} \frac{dR_c}{dt}\,dt = \frac{R_1 - R_0}{t_1 - t_0}(t_2 - t_1) - \frac{k}{2}(2R_m - R_1 - R_0)(t_2 - t_1) \quad (16)$$

Now the observed temperature change is $(R_2 - R_1)$ where R_2 and R_1 have been obtained graphically as explained above, and the cooling correction is given by (16). Calling δR the corrected value of the change of resistance corresponding to the change of temperature in the calorimeter

$$\delta R = R_2 - R_1 - \int_{t_1}^{t_2} \frac{dR_c}{dt}\,dt =$$

$$R_2 - R_1 + \frac{k}{2}(2R_m - R_1 - R_0)(t_2 - t_1) - \frac{R_1 - R_0}{t_1 - t_0}(t_2 - t_1) \quad (17)$$

where the value of $k/2$ is given by (13).

Thus δR is given in terms of four points, $(R_0 t_0)$, $(R_1 t_1)$, $(R_2 t_2)$, and $(R_3 t_3)$, and in terms of R_m. The four points are obtained by plotting the initial and final lines, and R_m is obtained by averaging the observed values of R during the heating period.

To convert δR into degrees C, use is made of a formula given by Dickinson and Mueller.[13] Starting with the Callendar-Griffiths equations for the resistance of platinum as a function of the temperature, they obtain.

$$\delta\theta = \frac{\dfrac{100}{R_{100}^\circ - R_0^\circ}}{\left(1 + \dfrac{\delta_c}{100} - \dfrac{2\delta_c}{100^2}\theta_m\right)}\delta R \quad (18)$$

where R_{100}°, R_0°, and δ_c, are the constants of the Callendar-Griffiths equation for the observing thermometer, and θ_m is the mean temperature, $\theta + \delta\theta/2$. θ_m need be known only approximately, and in this work was taken to be the temperature corresponding to R_m.

5. Callendar-Griffiths Equation for Resistance of Platinum as a Function of the Temperature.[14]

$$\theta - \theta_p = \delta_c\left(\frac{\theta}{100} - 1\right)\frac{\theta}{100} \quad (19)$$

$$\theta_p = 100\,\frac{R - R_0^\circ}{R_{100}^\circ - R_0^\circ} \quad (20)$$

13 Bull. Bur. of Standards, **9**, (1913), p. 483.
14 Reference 8, p. 201.

where θ = temperature in degrees Centigrade
θ_p = "platinum temperature" defined by (20)
R = resistance of thermometer at temperature θ.
$R_{100}°$ = resistance at 100°
$R_0°$ = resistance at 0°
δ_c = a third constant whose value depends on the purity of the platinum.

6. Calibration of Standard Thermometer.

Resistance at 0° C. Thermometer was deeply immersed in a thermos bottle containing commercial distilled water ice, finely shaved and soaked with distilled water. Preliminary measurements showed no appreciable difference between commercial ice and distilled water frozen in the laboratory. The average of six different determinations was taken.

Resistance at 100° C. Thermometer in a Regnault hypsometer equipped with manometer; hypsometer filled with distilled water. Alternate readings made on bridge and barometer. Barometer instrumental error determined by comparison with a standard 25 mm. bore barometer. Boiling points taken from Landolt and Bornstein's *Tabellen*. The average of four different determinations was taken.

Resistance at 218° C. Thermometer immersed in a naphthalene boiling apparatus, similar to the usual sulphur boiling tube, but equipped with two side condensing tubes. The purity of the naphthalene was tested, as usual, by measuring its melting point. In these measurements the thermometer tube was protected by an aluminium radiation and splash shield. Alternate readings were made on the bridge and the barometer. Boiling points were taken from Burgess and LeChatelier "Measurement of High Temperatures," p. 450. The average of three different determinations was taken.

7. Calibration of Observing Thermometer.

The observing thermometer in its calibration tube, and the standard thermometer, were both immersed in the constant temperature bath, which was set to regulate at some definite temperature. This bath temperature was not constant but fluctuated between narrow limits due to the regulation. Both thermometers followed these fluctuations but the observing thermometer lagged behind the standard. Comparisons were made by averaging the readings over at least one complete temperature wave for both thermometers. Seven comparisons for the two thermometers were thus made, three at

temperatures slightly above room temperature, two in the neighborhood of 60° C., and two in the neighborhood of 115° C. It requires comparison at three different temperatures to determine the constants of the Callendar-Griffiths equation. Of the three room temperature comparisons, two were at practically the same temperature, so these were averaged to give a single point, making two sets of comparisons of three each. From each of these sets the constants for the observing thermometer were computed, and then these two sets of constants were averaged to obtain the final accepted values.

8. **Mass of Ammonia.**

The mass of the empty container was determined by the average of three weighings, and the mass when loaded with ammonia, was determined by the average of six weighings. Weighings were made on a 2 Kilo Bunge Balance, using the Laboratory Standard weights.

9. **Volume of Ammonia Container.**

The volume of the ammonia container was determined by weighing the quantity of distilled water required to just fill it at room temperature. The specific volume of water at the observed temperature was taken from Landolt and Bornstein's *Tabellen*. The average of three determinations was taken as the value of the volume. Weighings were made on the 2 Kilo Bunge Balance using the Laboratory Standard Weights. The volume was again determined at 78° C. by the same method and no change was detected.

V. Experimental Observations and Data.

In this section are given all of the original observations and such other data as were used in the computation of the results, or were necessary to determine the precision of these measurements.

1. **Measurements of the Heat Capacity of the Apparatus:**

(a) When filled with Ammonia. (Ammonia Measurements.)
(b) When Empty. (Calibration Measurements.)

Explanation of the tables.— The first two columns give the bridge readings of the resistance of the observing thermometer as a function of the time. These readings were made at the end of each minute, The notations "Switch on" and "Switch off," indicate that at those instants the heater switch was thrown on and off, respectively. This

heater switch was thrown as nearly as possible at the exact end of the minute indicated in the first column. The temperature of the standard ohm, the standard cell, and the oil bath, were recorded at the beginning and end of each measurement. The potential drop readings given in the third and fourth columns, were made as rapidly as possible during the heating period, but not at definite time intervals. The values of R_0, R_1, R_2, and R_3, were obtained by plotting column 2 against column 1, and drawing the best initial and final lines. The values given were then read from the plot. The time intervals given in connection with these resistance readings, are the elapsed times between successive pairs of readings, as is indicated by their location in the table.

AMMONIA MEASUREMENT 1 AT 32°.9 C.
20 May, 1916

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	2.86457	Std. Ohm	Temp. Start: 23°.6 C.	End: 23°.6 C.	
1	6621	Std. Cell	Temp. Start: 21°.3 C.	End: 21°.4 C.	
2	6795	Oil Bath	Temp. Start: 4.21075	End: 4.21070	
3	6967			4.21060 Ohms Std. Therm.	
4	7146				
5	7305				
6	7480				
7	7650				
8	7820				
9	8000				
10	8168				
11	8338	Switch On.			
12	9083		0.40924	1.10819	1261.00
13	9740		0.40929	1.10824	
14	2.90361		0.40928	1.10822	
15	1005		0.40927	1.10800	
16	1619		0.40927	1.10797	
17	2225		0.40923	1.10787	
18	2825		0.40921	1.10785	
19	3436		0.40920	1.10770	
20	4017		0.40914	1.10762	
21	4600		0.40915	1.10755	
22	5191		0.40914	1.10730	
23	5757		0.40910	1.10731	
24	6325		0.40909	1.10726	
25	6896		0.40908	1.10728	
26	7469		0.40909	1.10723	
27	8035		0.40908	1.10721	
28	8585		0.40906	1.10722	
29	9140				
30	9677		R_0: 2.86625		
31	3.00221			10 Min.	
32	——	Switch Off.	R_1: 2.88338		
33	0701			21 Min.	
34	0749		R_2: 3.00300		
35	0807			24 Min.	
36	0870		R_3: 3.02592		
37	0939				
38	1009				
39	1083				
40	1156				
41	3.01235				
42	1317				
43	1397				
44	1480				
45	1562				
46	1642				
47	1740				
48	1833				
49	1919				
50	2015				
51	2108				
52	2208				
53	2312				
54	2403				
55	2497				
56	2589				

AMMONIA MEASUREMENT 2 AT 39°.6 C.

13 May, 1916.

Time in Min.	Ohms Obs. Therm.				
0	3.33529	Std. Ohm	Temp. Start:	23°.2 C.	End: 23°.3 C.
1	3671	Std. Cell	Temp. Start:	20°5. C.	End: 21°.0 C.
2	3815	Oil Bath	Temp. Start:	4.85440	End: 4.85488
3	3975			4.85475	4.85456
4	4129				Ohms Std. Therm.
5	4278				
6	4434				
7	4585				

		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
8	4740			
9	4903			
10	5056 Switch On.			
11	5756	0.40630	1.11249	1202.25
12	6379	0.40617	1.11233	±1.0
13	6992	0.40616	1.11225	
14	7572	0.40612	1.11202	
15	8161	0.40603	1.11200	
16	8735	0.40596	1.11188	
17	9304	0.40592	1.11169	
18	9863	0.40584	1.11164	
19	3.40402	0.40583	1.11157	
20	0954	0.40577	1.11140	
21	1505	0.40574		
22	2060			
23	2615	R_0: 3.33513		
24	3170		10 Min.	
25	3717	R_1: 3.35056		
26	4253		20 Min.	
27	4802	R_2: 3.46166		
28	5340		15 Min.	
29	5878	R_3: 3.47710		
30	6417 Switch Off.			
31	6392			
32	6448			
33	6517			
34	6605			
35	6697			
36	6785			
37	6887			
38	6991			
39	7096			
40	7197			
41	7300			
42	7402			
43	7504			
44	7606			
45	——			
46	7828			
47	7942			
48	8057			
49	8173			
50	8283			
51	8404			
52	8513			
53	8628			
54	8745			
55	8859			

AMMONIA MEASUREMENT 3 AT 40°.6 C.

20 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	3.38607	Std. Ohm Temp. Start: 23°.1 C. End: 23°.0 C.			
1	8720	Std. Cell Temp. Start: 20°.9 C. End: 20°.5 C.			
2	8835	Oil Bath Temp. Start: 4.97432 End:			
3	8960	4.97446 4.97540			
4	9092	Ohms Std. Therm.			
5	9221				
6	9347				
7	9482				
8	9612				
9	9749				
10	9891	Switch On.			
11	——		0.40850	1.10521	1139.10
12	3.41173		0.40823	1.10430	
13	1775		0.40784	1.10343	
14	2361		0.40747	1.10225	
15	2943		0.40713	1.10156	
16	3510		0.40686	1.10073	
17	4066		0.40661	1.10021	
18	4620		0.40623	1.09887	
19	5163		0.40595	1.09797	
20	5703		0.40571	1.09750	
21	6245		0.40553	1.09669	
22	6773		0.40525	1.09628	
23	7315				
24	7818	R_0: 3.38538			
25	8340	10 Min.			
26	8873	R_1: 3.39891			
27	9374	19 Min.			
28	9881	R_2: 3.50198			
29	3.50390	Switch Off. 25 Min.			
30	0357	R_3: 3.52309			
31	——				
32	0453				
33	——				
34	0568				
35	0642				
36	0724				
37	0802				
38	0891				
39	0985				
40	1073				
41	1170				
42	1270				
43	1362				
44	1458				
45	1546				
46	1635				
47	1719				
48	1804				
49	1890				
50	1971				
51	2057				
52	——				
53	2225				
54	——				
55	2396				

AMMONIA MEASUREMENT 4 AT 51°.9 C.

14 May, 1916.

Time in Min.	Ohms Obs. Therm.						
0	4.17268		Std. Ohm	Temp. Start:	23°.1 C.	End:	22°.9 C.
1	7414		Std. Cell	Temp. Start:	20°.3 C.	End:	20°.0 C.
2	7556		Oil Bath	Temp. Start:	6.16097	End:	6.16071
3	7709				6.16100		6.16072
4	7850						Ohms Std. Therm.
5	7994						
6	8152						
7	8305						
8	8452			P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.	
9	8601						
10	8756	Switch On.					
11	9442	5 Sec.		0.40635	1.11171	1196.05	
12	4.20065	late.		0.40623	1.11170		
13	0645			0.40623	1.11148		
14	1240			0.40622	1.11160		
15	1822			0.40616	1.11142		
16	2396			0.40613	1.11132		
17	2965			0.40610	1.11132		
18	3525			0.40602	1.11130		
19	4082			0.40600	1.11112		
20	4638			0.40577	1.11100		
21	5199				1.11070		
22	5741						
23	6281			R_0: 4.17272			
24	6823				10 Min.		
25	7361			R_1: 4.18764			
26	7895				20 Min.		
27	8422			R_2: 4.29700			
28	8949				25 Min.		
29	9481			R_3: 4.32073			
30	4.30004	Switch Off.					
31	4.29948						
32	4.30004						
33	0065						
34	0140						
35	0222						
36	0304						
37	0382						
38	0476						
39	0570						
40	0655						
41	0752						
42	0847						
43	0942						
44	1035						
45	1131						
46	1223						
47	1318						
48	1408						
49	1504						
50	1598						
51	1691						
52	1794						
53	1886						
54	1980						
55	2080						

AMMONIA MEASUREMENT 5 AT 62°.8 C.

15 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	4.92585	Std. Ohm Temp. Start:	24°.2 C.	End: 24°.1 C.	
1	2685	Std. Cell Temp. Start:	21°.5 C.	End: 21°.5 C.	
2	2793	Oil Bath Temp. Start:	7.21045	End: 7.21059	
3	2907		7.21085	7.21067	
4	3025		7.21090	Ohms Std. Therm.	
5	3136				
6	3256				
7	3374				
8	3491				
9	3612				
10	3732				
11	3850	Switch On.			
12	4545		0.40997	1.11939	1199.40
13	5137		0.40993	1.11938	
14	5702		0.40986	1.11923	
15	6265		0.40978	1.11916	
16	6806		0.40974	1.11903	
17	7346		0.40967	1.11880	
18	7881		0.40964	1.11873	
19	8415		0.40958	1.11870	
20	8931		0.40953	1.11852	
21	9460		0.40946	1.11851	
22	9986		0.40944	1.11832	
23	5.00486		0.40939	1.11824	
24	0982			1.11820	
25	1490			1.11812	
26	1990				
27	2496		R_0: 4.92666		
28	2991			10 Min.	
29	3474		R_1: 4.93850		
30	3967			20 Min.	
31	4461	Switch Off.	R_2: 5.04129		
32	4368			25 Min.	
33	4385		R_3: 5.05776		
34	4416				
35	4456				
36	4510				
37	4557				
38	4612				
39	4667				
40	4731				
41	4794				
42	4853				
43	4918				
44	4983				
45	5050				
46	5115				
47	5183				
48	5253				
49	5315				
50	5379				
51	5447				
52	5515				
53	5578				
54	5647				
55	5711				
56	5776				

AMMONIA MEASUREMENT 6 AT 72°.7 C.
15 May, 1916.

Time in Min.	Ohms Obs. Therm.				
0	5.60004	Std. Ohm	Temp. Start:	26°.3 C.	End: 26°.7 C.
1	0069	Std. Cell	Temp. Start:	24°.7 C.	End: 24°.7 C.
2	0131	Oil Bath	Temp. Start:	8.15018	End: 8.15175
3	0202			8.15013	8.15165
4	0280				Ohms Std. Therm.
5	0355				
6	0432				
7	0507				

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
8	0586				
9	0666				
10	0745	Switch On.			
11	1406		0.40996	1.11932	1200.05
12	1943		0.40955	1.11806	
13	2475		0.40922	1.11800	
14	2967		0.40931	1.11821	
15	3468		0.40921	1.11772	
16	3946		0.40903	1.11736	
17	4431		0.40905	1.11722	
18	4912		0.40891	1.11712	
19	5382		0.40886	1.11701	
20	5841		0.40945	1.11852	
21	6294		0.40943	1.11852	
22	6752		0.40930		
23	7205				
24	7645		R_0: 5.59985		
25	8107			10 Min.	
26	8557		R_1: 5.60737		
27	8989			20 Min.	
28	9439		R_2: 5.69975		
29	9875			25 Min.	
30	5.70327	Switch Off.	R_3: 5.70556		
31	0177				
32	0151				
33	0142				
34	0137				
35	0147				
36	0150				
37	0155				
38	0169				
39	0190				
40	0204				
41	0228				
42	0246				
43	0273				
44	0301				
45	0327				
46	0357				
47	0379				
48	0404				
49	0443				
50	0442	Shifted 0.1 Ohm Plug.			
51	0468				
52	0487				
53	0505				
54	0533				
55	0556				

AMMONIA MEASUREMENT 7 AT 83°.2 C.
15 May, 1916.

Time in Min.	Ohms Obs. Therm.					
0	6.30702	Std. Ohm	Temp. Start:	25°.6 C.	End:	25°.5 C.
1	0788	Std. Cell	Temp. Start:	23°.0 C.	End:	22°.8 C.
2	0870	Oil Bath	Temp. Start:	9.23486	End:	9.23515
3	0955			9.23495		9.23510
4	1040					Ohms Std. Therm.
5	1135					
6	1226					
7	1316					
8	1407		P. D. across Standard Ohm in Volts.		P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
9	1500					
10	1590	Switch On.				
11	2245		0.40842		1.11511	1200.10
12	2805		0.40841		1.11516	
13	3330		0.40840		1.11510	
14	3856		0.40840		1.11503	
15	4362		0.40838		1.11480	
16	4850		0.40836		1.11468	
17	5333		0.40843		1.11472	
18	5815		0.40835		1.11443	
19	6293		0.40832		1.11440	
20	6770		0.40825		1.11420	
21	7242		0.40823		1.11414	
22	7706		0.40822		1.11403	
23	8178		0.40822		1.11400	
24	8640		0.40820		1.11386	
25	9099					
26	9561		R_0: 6.30685			
27	6.40011				10 Min.	
28	0457	Shifted Plug.	R_1: 6.31590			
29	0900				20 Min.	
30	1348	Switch Off.	R_2: 6.41007			
31	1240				25 Min.	
32	1226		R_3: 6.41989			
33	1240					
34	1252					
35	1269					
36	1296					
37	1321					
38	1353					
39	1382					
40	1411					
41	1442					
42	1483					
43	1517					
44	1550					
45	1586					
46	1629					
47	1674					
48	1709					
49	1753					
50	1798					
51	1838					
52	1874					
53	1910					
54	1946					
55	1985					

Ammonia Measurement 8 at 92°.7 C.

16 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds
0	6.95560	Std. Ohm Temp. Start: 26°.2 C. End: 26°.7 C.			
1	5652	Std. Cell Temp. Start: 25°.0 C. End: 25°.0 C.			
2	5758	Oil Bath Temp. Start: 10.26575 End: 10.26520			
3	5851	10.26560 10.26487			
4	5940	Ohms Std. Therm.			
5	6040				
6	6134				
7	6226				
8	6322				
9	6407				
10	6503	Switch On.			
11	7160		0.40896	1.11252	1200.35
12	7702		0.40890	1.11235	
13	8221		0.40881	1.11230	
14	8719		0.40876	1.11220	
15	9218		0.40872	1.11202	
16	9715		0.40867	1.11192	
17	7.00203		0.40865	1.11182	
18	0656		0.40862	1.11167	
19	1133		0.40855	1.11153	
20	1602		0.40852	1.11144	
21	2072		0.40847	1.11136	
22	2534		0.40844	1.11128	
23	2996		0.40838	1.11116	
24	3450		0.40835	1.11105	
25	3895				
26	4347		R_0: 6.95570		
27	4786		10 Min.		
28	5241		R_1: 6.96510		
29	5677		20 Min.		
30	6117	Switch Off.	R_2: 7.05834		
31	5995		25 Min.		
32	5987		R_3: 7.06697		
33	5991				
34	6005				
35	6030				
36	6055				
37	6088				
38	6114				
39	6147				
40	6182				
41	6211				
42	6245				
43	6284				
44	6313				
45	6348				
46	6381				
47	6416				
48	6452				
49	6485				
50	6518				
51	6558				
52	6595				
53	6632				
54	6666				
55	6705				

AMMONIA MEASUREMENT 9 AT 102°.9 C.

16 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	7.64368	Std. Ohm Temp. Start: 27°.8 C. End: 27°.3 C.			
1	4423	Std. Cell Temp. Start: 24°.6 C. End: 24°.0 C.			
2	4473	Oil Bath Temp. Start: 11.24065 End: 11.24784			
3	4524	11.24062 Ohms Std. Therm.			
4	4585				
5	4647				
6	4700				
7	4766				
8	4834				
9	4895				
10	4962	Switch On.			
11	5563		0.40884	1.11224	1200.40
12	6070		0.40865	1.11160	
13	6563		0.40860	1.11133	
14	7035		0.40847	1.11121	
15	7496		0.40836	1.11101	
16	7957		0.40827	1.11053	
17	——		0.40815	1.11044	
18	8843		0.40826	1.11069	
19	9291		0.40784	1.11000	
20	9728		0.40800	1.11002	
21	7.70151		0.40803	1.10972	
22	0580		0.40790	1.10940	
23	1019				
24	1442		R_0: 7.64339		
25	1860			10 Min.	
26	2270		R_1: 7.64957		
27	2687			20 Min.	
28	3111		R_2: 7.73574		
29	3514			25 Min.	
30	3930	Switch Off.	R_3: 7.74135		
31	3792				
32	3757				
33	3743				
34	3745				
35	3750				
36	3753				
37	3760				
38	3777				
39	3795				
40	3806				
41	3831				
42	3846				
43	3871				
44	3881				
45	3903				
46	3930				
47	3955				
48	3967				
49	3993				
50	4020				
51	4038				
52	4065				
53	4090				
54	4110				
55	4138				

Ammonia Measurement 10 at 102°.9 C.

17 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	7.63535	Std. Ohm	Temp. Start:	25°.3 C.	End: 25°.2 C.
1	3635	Std. Cell	Temp. Start:	22°.5 C.	End: 22°.4 C.
2	3736	Oil Bath	Temp. Start:	11.27404	End: 11.27417
3	3835			11.27431	Ohms Std. Therm.
4	3936				
5	4052				
6	4150				
7	4242				
8	4336				
9	4445				
10	4545	Switch On.			
11	5180		0.40956	1.10734	1199.50
12	5729		0.40902	1.10642	
13	6246		0.40884	1.10402	
14	6735		0.40797	1.10370	
15	7241		0.40787	1.10307	
16	7717		0.40776	1.10279	
17	8195		0.40767	1.10263	
18	8666		0.40756	1.10256	
19	9150		0.40748	1.10224	
20	9614		0.40736	1.10217	
21	7.70083		0.40732	1.10178	
22	0530		0.40728	1.10173	
23	0970		0.40727	1.10158	
24	1423				
25	1885		R_0: 7.63534		
26	2325			10 Min.	
27	2768		R_1: 7.64545		
28	3210			20 Min.	
29	3650		R_2: 7.73778		
30	4079	Switch Off.		25 Min.	
31	3976		R_3: 7.74934		
32	3977				
33	3985				
34	4018				
35	4045				
36	4077				
37	4115				
38	4154				
39	4200				
40	4238				
41	4286				
42	4335				
43	4377				
44	4423				
45	4465				
46	4513				
47	4563				
48	4608				
49	4652				
50	4685				
51	4742				
52	4790				
53	4840				
54	4890				
55	4941				

AMMONIA MEASUREMENT 11 AT 113°.0 C.

16 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	8.31905	Std. Ohm Temp. Start: 25°.3 C. End: 25°.1 C.			
1	1979	Std. Cell Temp. Start: 22°.6 C. End: 22°.5 C.			
2	2060	Oil Bath Temp. Start: 12.28816 End: 12.28762			
3	2130	12.28725 Ohms Std. Therm.			
4	2202				
5	2273				
6	——				
7	2390				
8	2463				
9	2550				
10	2623	Switch On.			
11	3235		0.40502	1.09762	1200.15
12	3730		0.40501	1.09722	
13	4197		0.40500	1.09712	
14	4659		0.40495	1.09715	
15	5107		0.40494	1.09714	
16	5569		0.40492	1.09703	
17	6023		0.40490	1.09690	
18	6460		0.40485	1.09690	
19	6891		0.40485	1.09686	
20	7317		0.40483	1.09675	
21	7737		0.40479	1.09673	
22	8162		0.40479	1.09662	
23	8570		0.40476	1.09655	
24	8990				
25	9402		R_0: 8.31908		
26	9816			10 Min.	
27	8.40223		R_1: 8.32622		
28	0607			20 Min.	
29	1031		R_2: 8.41067		
30	1429	Switch Off.		25 Min.	
31	1303		R_3: 8.41845		
32	1279				
33	1276				
34	1280				
35	1294				
36	1305				
37	1325				
38	1345				
39	1365				
40	1388				
41	1414				
42	1446				
43	1468				
44	1506				
45	1529				
46	1565				
47	1593				
48	1627				
49	1659				
50	1690				
51	1718				
52	1752				
53	1784				
54	1814				
55	1847				

AMMONIA MEASUREMENT 12 AT 122°.5 C.
18 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds
0	8.94585	Std. Ohm Temp. Start: 26°.1 C. End: 25°.2 C.			
1	4664	Std. Cell Temp. Start: 22°.0 C. End: 21°.8 C.			
2	4765	Oil Bath Temp. Start: 13.23410 End: 13.22465			
3	4841	13.23402 Ohms Std. Therm.			
4	4928				
5	5021				
6	5104				
7	5200				
8	5285				
9	5377				
10	5463	Switch On.			
11	6072		0.41029	1.10759	1200.30
12	6566		0.41025	1.10759	
13	7059		0.41023	1.10749	
14	7512		0.41020	1.10742	
15	7977		0.41012	1.10726	
16	8440		0.40983	1.10645	
17	8900		0.40983	1.10645	
18	9335		0.40983	1.10659	
19	9776		0.40985	1.10657	
20	9.00201		0.40984	1.10654	
21	0626		0.40983	1.10655	
22	1066		0.40987	1.10656	
23	1503		0.40988	1.10669	
24	1925		0.40990	1.10680	
25	2351		0.40993	1.10680	
26	2772		0.40992		
27	3200				
28	3613		R_0: 8.94573		
29	4034		10 Min.		
30	4465	Switch Off.	R_1: 8.95464		
31	4338		20 Min.		
32	4317		R_2: 9.04112		
33	4337		25 Min.		
34	4356		R_3: 9.05167		
35	4376				
36	4407				
37	4437				
38	4470				
39	4506				
40	4541				
41	4577				
42	4620				
43	4657				
44	4706				
45	4745				
46	4790				
47	4830				
48	4877				
49	4910				
50	4968				
51	——				
52	5046				
53	5082				
54	5123				
55	5168				

CALIBRATION MEASUREMENT 1 AT 23°.2 C.

8 June, 1916.

Time in Min.	Ohms Obs. Therm.					
0	2.21430	Std. Ohm	Temp. Start:	26° 8 C.	End:	26°.8 C.
1	1555	Std. Cell	Temp. Start:	24°.4 C.	End:	24°.3 C.
2	1710	Oil Bath	Temp. Start:	3.10262	End:	3.10415
3	1823			3.10248		3.10381
4	1963					Ohms Std. Therm.
5	——	Made Reading of				
6	1987	Bath Temperature.				
7	2072					
8	2213					
9	2350					
10	2489	Switch On.				
11	——					
12	4367					
13	5170		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.	
14	5930					
15	6670					
16	7430		0.40889	1.10820	958.40	
17	8138		0.40880	1.10803		
18	8847		0.40876	1.10786		
19	9575		0.40871	1.10770		
20	2.30242		0.40865	1.10753		
21	0911		0.40860	1.10730		
22	1583		0.40852	1.10714		
23	2250					
24	——					
25	3563					
26	4213	Switch Off.				
27	4001		R_0: 2.21098			
28	3892			10 Min.		
29	3870		R_1: 2.22489			
30	3869			16 Min.		
31	3885		R_2: 2.33392			
32	3921			25 Min.		
33	3965		R_3: 2.35042			
34	4000					
35	4045					
36	4090					
37	4147					
38	——					
39	4264					
40	4315					
41	4385					
42	4440					
43	4508					
44	4575					
45	4641					
46	4712					
47	4780					
48	4850					
49	4915					
50	4995					
51	5065					

CALIBRATION MEASUREMENT 2 AT 26°.9 C.

26 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	2.48690	Std. Ohm Temp. Start:	29°.0 C.	End: 29°.0 C.	
1	8797	Std. Cell Temp. Start:	26° 5 C.	End: 26°.5 C.	
2	8912	Oil Bath Temp. Start:	3.52491	End: 3.52006	
3	9026		3.52524	Ohms Std. Therm.	
4	9141				
5	9265				
6	9380				
7	9502				
8	9625				
9	9741				
10	9868	Switch On.			
11	2.50830	(?)	0.40920	1.11094	599.33
12	1710		0.40916	1.11088	
13	2500		0.40913	1.11074	
14	3250		0.40907	1.11061	
15	3987		0.40904	1.11053	
16	4703		0.40899	1.11043	
17	5406		0.40894	1.11030	
18	6100		0.40890	1.11019	
19	6785				
20	7467	Switch Off.			
21	7285				
22	7212				
23	7205		R_0: 2.48658		
24	7234			10 Min.	
25	7274		R_1: 2.49867		
26	7326			10 Min.	
27	7387		R_2: 2.56631		
28	7452			25 Min.	
29	7521		R_3: 2.58931		
30	7595				
31	7673				
32	7756				
33	7839				
34	7919				
35	8010				
36	8102				
37	8192				
38	8281				
39	8373				
40	8445				
41	8561				
42	8651				
43	8746				
44	8838				
45	8932				

CALIBRATION MEASUREMENT 3 AT 39°.8 C.

9 June, 1916.

Time in Min.	Ohms Obs. Therm.				
0	3.37685	Std. Ohm	Temp. Start:	24°.6 C.	End: 24°.6 C.
1	7750	Std. Cell	Temp. Start:	23°.0 C.	End: 23°.0 C.
2	7817	Oil Bath	Temp. Start:	4.86603	End: 4.86585
3	7887			4.86599	Ohms Std. Therm.
4	7965				
5	8036				
6	8114				
7	8198				
8	8280				
9	8357				

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
10	8436	Switch On.			
11	9005		0.30946	0.83889	900.05
12	9510		0.30941	0.83884	
13	9958		0.30940	0.83883	
14	3.40403	?	0.30940	0.83885	
15	0812		0.30939	0.83882	
16	1230		0.30938	0.83881	
17	1640		0.30936	0.83880	
18	2050		0.30936	0.83880	
19	2445		0.30933	0.83874	
20	2842		0.30933	0.83870	
21	3229				
22	3611		R_0: 3.37639		
23	3992			10 Min.	
24	4371		R_1: 3.38436		
25	4759	Switch Off.		15 Min.	
26	4663		R_2: 3.44303		
27	4594			25 Min.	
28	4585		R_3: 3.45432		
29	4595				
30	4613				
31	4637				
32	4660				
33	4696				
34	4733				
35	4772				
36	4810				
37	4846				
38	4889				
39	4930				
40	4983				
41	5023				
42	5069				
43	5116				
44	5162				
45	5196				
46	5247				
47	5295				
48	5340				
49	5387				
50	5432				

CALIBRATION MEASUREMENT 4 AT 39°.8 C.
10 June, 1916.

Time in Min.	Ohms Obs. Therm.					
0	3.37685	Std. Ohm	Temp. Start:	23°.2 C.	End:	23°.7 C.
1	7777	Std. Cell	Temp. Start:	23°.1 C.	End:	23°.1 C.
2	7872	Oil Bath	Temp. Start:	4.86571	End:	4.86577
3	7973			4.86632	Ohms Std. Therm.	
4	8075					
5	8173					
6	8272					
7	8365					
8	8468		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds	
9	8565					
10	8659	Switch On.				
11	9303		0.32564	0.88242	900.10	
12	9871		0.32537	0.88189		
13	3.40386		0.32512	0.88121		
14	0852		0.32500	0.88060		
15	1332		0.32478	0.88035		
16	1787		0.32454	0.87953		
17	2252		0.32436	0.87911		
18	2692		0.32418	0.87863		
19	3144		0.32398	0.87800		
20	3570					
21	4015		R_0: 3.37691			
22	4462			10 Min.		
23	4883		R_1: 3.38659			
24	5304			15 Min.		
25	5712	Switch Off.	R_2: 3.45202			
26	5598			25 Min.		
27	5541		R_3: 3.46524			
28	5535					
29	5547					
30	5571					
31	5603					
32	5635					
33	5677					
34	5715					
35	5758					
36	5801					
37	5849					
38	5900					
39	5944					
40	5997					
41	6042					
42	6099					
43	6150					
44	6199					
45	6260					
46	6312					
47	6365					
48	6412					
49	6470					
50	6522					

CALIBRATION MEASUREMENT 5 AT 40°.2 C.

10 June, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds
0	3.41111	Std. Ohm Temp. Start: 24°.2 C. End: 24°.2 C.			
1	1191	Std. Cell Temp. Start: 22°.3 C. End: 22°.1 C.			
2	1268	Oil Bath Temp. Start: 4.86612 End: 4.86620			
3	1347	Ohms Std. Therm.			
4	1425				
5	1503				
6	1585				
7	1664				
8	1748				
9	1825				
10	1908	Switch On.			
11	2464		0.30826	0.83583	900.34
12	2969		0.30824	0.83580	
13	3410		0.30822	0.83572	
14	3844		0.30821	0.83572	
15	4263		0.30820	0.83567	
16	4670		0.30819	0.83562	
17	5065		0.30817	0.83556	
18	5468		0.30814	0.83552	
19	5857		0.30816	0.83550	
20	6253		0.30812	0.83545	
21	6632		0.30813	0.83545	
22	7008				
23	7398				
24	7770				
25	8154	Switch Off			
26	8037				
27	7973				
28	7962		R_0: 3.41101		
29	7969			10 Min.	
30	7982		R_1: 3.41908		
31	8001			15 Min.	
32	8028		R_2: 3.47679		
33	8049			25 Min.	
34	8081		R_3: 3.48693		
35	8109				
36	8143				
37	8175				
38	8217				
39	8250				
40	8287				
41	8319				
42	8362				
43	8404				
44	8443				
45	8482				
46	8518				
47	8567				
48	8611				
49	8653				
50	8696				

Calibration Measurement 6 at 40°.2 C.

10 June, 1916.

Time in Min.	Ohms Obs. Therm.				
0	3.39803	Std. Ohm	Temp. Start:	24°.0 C.	End: 23°.9 C.
1	9921	Std. Cell	Temp. Start:	22°.1 C.	End: 22°.0 C.
2	3.40042	Oil Bath	Temp. Start:	4.86600	End: 4.86680
3	0162				Ohms Std. Therm.
4	0288				
5	0408				
6	0530				
7	0653				
8	0775				
9	0890				

		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts	Heating Period ($t_2 - t_1$) in Seconds.
10	1013 Switch On.			
11	1605	0.30474	0.82624	900.15
12	2134	0.30474	0.82623	
13	2623	0.30473	0.82620	
14	3080	0.30472	0.82629	
15	3530	0.30475	0.82626	
16	3978	0.30473	0.82620	
17	4413	0.30469	0.82613	
18	4845	0.30470	0.82617	
19	5265	0.30470	0.82617	
20	5685	0.30471	0.82616	
21	6103	0.30470	0.82614	
22	6514			
23	6920	R_0: 3.39803		
24	7321		10 Min.	
25	7725 Switch Off.	R_1: 3.41013		
26	7650		15 Min.	
27	7642	R_2: 3.47308		
28	7668		25 Min.	
29	7718	R_3: 3.49288		
30	7771			
31	7840			
32	7900			
33	7972			
34	8043			
35	8115			
36	8193			
37	8271			
38	8341			
39	8421			
40	8495			
41	8577			
42	8656			
43	8734			
44	8817			
45	8895			
46	8970			
47	9052			
48	9130			
49	9213			
50	9288			

CALIBRATION MEASUREMENT 7 AT 40°.2 C.

27 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	3.37349	Std. Ohm	Temp. Start:	26°.8 C.	End: 27° 2 C.
1	7494	Std. Cell	Temp. Start:	24°.7 C.	End: 25°.0 C.
2	7656	Oil Bath	Temp. Start:	4.96933	End: 4.96923
3	7806			4.97008	Ohms Std. Therm.
4	7975				
5	8133				
6	8303				
7	8460				
8	8618				
9	8787				
10	8947	Switch On.			
11	9980		0.40935	1.11095	901.10
12	3.40855		0.40955	1.11092	
13	1691		0.40952	1.11082	
14	2469		0.40945	1.11070	
15	3241		0.40944	1.11065	
16	3988		0.40939	1.11050	
17	4723		0.40934	1.11036	
18	5444		0.40928	1.11029	
19	6173		0.40927	1.11013	
20	6872		0.40919	1.11000	
21	7574		0.40915	1.10978	
22	8277		0.40907		
23	8966				
24	9636		R_0: 3.37316		
25	3.50331	Switch Off.		10 Min.	
26	0172		R_1: 3.38949		
27	0091			15 Min.	
28	0095		R_2: 3.49522		
29	0120			25 Min.	
30	0171		R_3: 3.51870		
31	0229				
32	0290				
33	0360				
34	0414				
35	0495				
36	0578				
37	0660				
38	0749				
39	0827				
40	0927				
41	1018				
42	1110				
43	1200				
44	1290				
45	1385				
46	1500				
47	1593				
48	1683				
49	1773				
50	1867				

Calibration Measurement 8 at 61°.0 C.

27 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	4.78922	Std. Ohm Temp. Start:	27°.8 C.	End: 27°.6 C.	
1	9053	Std. Cell Temp. Start:	25°.5 C.	End: 25°.0 C.	
2	9186	Oil Bath Temp. Start:	7.04726	End: 7.04743	
3	9318		7.04722	Ohms Std. Therm.	
4	9444				
5	9565				
6	9697				
7	9832				
8	9957				
9	4.80087				
10	0199	Switch On.			
11	1172		0.40922	1.10692	900.30
12	2011		0.40872	1.10609	
13	2781		0.40861	1.10587	
14	3500		0.40851	1.10560	
15	4216		0.40843	1.10556	
16	4900		0.40837	1.10532	
17	5586		0.40831	1.10530	
18	6245		0.40834	1.10532	
19	6903		0.40831	1.10513	
20	7560		0.40826	1.10502	
21	8182		0.40822	1.10495	
22	8820				
23	9446		R_0: 4.78922		
24	4.90060			10 Min.	
25	0671	Switch Off.	R_1: 4.80215		
26	0443			15 Min.	
27	0303		R_2: 4.89891		
28	0252			25 Min.	
29	0237		R_3: 4.90977		
30	0240				
31	0252				
32	0272				
33	0293				
34	0323				
35	0355				
36	0388				
37	0425				
38	0465				
39	0502				
40	0545				
41	0581				
42	0629				
43	0673				
44	0714				
45	0747				
46	0796				
47	0841				
48	0891				
49	0934				
50	0984				

CALIBRATION MEASUREMENT 9 AT 79°.8 C.

27 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds
0	6.07542	Std. Ohm Temp. Start: 27°.9 C. End: 27°.8 C.			
1	7660	Std. Cell Temp. Start: 25°.3 C. End: 25°.5 C.			
2	7790	Oil Bath Temp. Start: 9.04247 End: 9.04215			
3	7920			9.04306 Ohms Std. Therm.	
4	8043				
5	8169				
6	8302				
7	8435				
8	8567				
9	8695				
10	8824	Switch On.			
11	9781		0.41134	1.11312	900.00
12	6.10645		0.41124	1.11295	
13	1425		0.41121	1.11286	
14	2149		0.41118	1.11276	
15	2853		0.41114	1.11266	
16	3555		0.41112	1.11257	
17	4234		0.41107	1.11248	
18	4905		0.41105	1.11240	
19	5574		0.41100	1.11231	
20	6233		0.41096	1.11226	
21	6876		0.41096	1.11218	
22	7518		0.41093	1.11211	
23	8150				
24	8793		R_0: 6.07508		
25	9432	Switch Off.		10 Min.	
26	9212		R_1: 6.08824		
27	9091			15 Min.	
28	9065		R_2: 6.18566		
29	9079			25 Min.	
30	9106		R_3: 6.20430		
31	9136				
32	9179				
33	9233				
34	9286				
35	9348				
36	9423				
37	9482				
38	9545				
39	9615				
40	9677				
41	9750				
42	9820				
43	9895				
44	9981				
45	6.20057				
46	0130				
47	0208				
48	0282				
49	0357				
50	0430				

CALIBRATION MEASUREMENT 10 AT 82°.7 C.
28 May, 1916

Time in Min.	Ohms Obs. Therm.				
0	6.27210	Std. Ohm	Temp. Start:	27°.3 C.	End: 26°.8 C.
1	7301	Std. Cell	Temp. Start:	24°.5 C.	End: 24°.5 C.
2	7391	Oil Bath	Temp. Start:	9.18862	End: 9.18855
3	7491			9.18879	Ohms Std. Therm.
4	7580				
5	7670				
6	7760				
7	7849				
8	7935		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
9	8023				
10	8106	Switch On.			
11	9038		0.40937	1.10812	899.18
12	9820		0.40929	1.10781	
13	6.30539		0.40924	1.10770	
14	1236		0.40916	1.10749	
15	1886		0.40911	1.10734	
16	2525		0.40906	1.10729	
17	3162		0.40903	1.10705	
18	3781		0.40894	1.10687	
19	4403		0.40887	1.10667	
20	5000		0.40880	1.10652	
21	5593		0.40875	1.10638	
22	6165		0.40868	1.10623	
23	6760				
24	7315				
25	7900	Switch Off.			
26	7630				
27	7461		R_0: 6.27225		
28	7389			10 Min.	
29	7342		R_1: 6.28112		
30	7325			15 Min.	
31	7305		R_2: 6.37053		
32	7291			25 Min.	
33	7290		R_3: 6.37540		
34	7291				
35	7296				
36	7287				
37	7306				
38	7311				
39	7330				
40	7345				
41	7362				
42	7384				
43	7403				
44	7417				
45	7435				
46	7457				
47	7482				
48	7505				
49	7520				
50	7537				

CALIBRATION MEASUREMENT 11 AT 100°.6 C.

29 May, 1916.

Std. Ohm Temp. Start: 26°.0 C. End: 25°.2 C.
Std. Cell Temp. Start: 24°.2 C. End: 24°.4 C.
Oil Bath Temp. Start: 11.03763 End: 11.03691
11.03764 Ohms Std. Therm.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	7.48176				
1	8247				
2	8330				
3	8415				
4	8487				
5	8573				
6	8655				
7	8748				
8	8841				
9	8928				
10	9017	Switch On.			
11	9936		0.40794	1.10202	899.20
12	——		0.40787	1.10171	
13	7.51430		0.40767	1.10100	
14	2100		0.40745	1.10043	
15	2741		0.40715	1.10013	
16	3365		0.40705	1.09935	
17	3994		0.40684	1.09900	
18	4590		0.40673	1.09883	
19	5193		0.40665	1.09844	
20	5776		0.40648	1.09792	
21	6362		0.40631	1.09751	
22	6945				
23	7505		R_0: 7.48128		
24	8072			10 Min.	
25	8616	Switch Off.	R_1: 7.49017		
26	8352			15 Min.	
27	8195		R_2: 7.57826		
28	8125			25 Min.	
29	8087		R_3: 7.58326		
30	8063				
31	8051				
32	8040				
33	8043				
34	8051				
35	8055				
36	8065				
37	8083				
38	8085				
39	8104				
40	8124				
41	8144				
42	8161				
43	8182				
44	8204				
45	8217				
46	8247				
47	8265				
48	8285				
49	8314				
50	8332				

CALIBRATION MEASUREMENT 12 AT 121°.9 C.
29 May, 1916.

Time in Min.	Ohms Obs. Therm.		P. D. across Standard Ohm in Volts.	P. D. across Small Coil of Volt Box in Volts.	Heating Period ($t_2 - t_1$) in Seconds.
0	8.91155	Std. Ohm Temp. Start: 25°.7 C. End: 25°.6 C.			
1	1217	Std. Cell Temp. Start: 23°.5 C. End: 23°.3 C.			
2	1275	Oil Bath δTemp. Start: 13.08932 End: 13.08922			
3	1333	13.08925 Ohms Std. Therm.			
4	1400				
5	1460				
6	1516				
7	1572				
8	1624				
9	1680				
10	1745	Switch On.			
11	2625		0.40919	1.10484	900.10
12	3383		0.40918	1.10479	
13	4061		0.40917	1.10476	
14	4679		0.40916	1.10465	
15	5302		0.40915	1.10465	
16	5884		0.40913	1.10459	
17	6446		0.40913	1.10458	
18	7018		0.40912	1.10456	
19	7571		0.40911	1.10454	
20	8118		0.40910	1.10453	
21	8672		0.40909	1.10452	
22	9205		0.40906	1.10444	
23	9750		0.40905	1.10441	
24	9.00268				
25	0781	Switch Off.	R_0: 8.91157		
26	0478			10 Min.	
27	0285		R_1: 8.91745		
28	0167			15 Min.	
29	0096		R_2: 8.99948		
30	0041			25 Min.	
31	0001		R_3: 8.99709		
32	8.99962				
33	9918				
34	9890				
35	9879				
36	9860				
37	9847				
38	9835				
39	9818				
40	9805				
41	9801				
42	9789				
43	9775				
44	9771				
45	9762				
46	9745				
47	9740				

2. **Ratio of Volt Box Coils.** See Part IV, Sec. 3.

Column 4 gives the potential drop across the large coil of the volt box including the leads to the heating coil; column 5 gives the potential drop across the small coil of the volt box. The drop across the small coil was read, in each case, immediately after the drop across the large coil. The temperature readings are room temperatures in the neighborhood of the coils.

Determination of Ratio of Volt Box Coils.
10 May 1916.

Wolff Potentiometer #2868.
Weston Cadmium Cell #1458.

No.	Time Mins.	Temperature °C.	Potentiometer Readings	
1	0	23.0	1.25451	0.25020
2	3		1.25426	0.25019
3	5		1.25410	0.25014
4	7	23.1	1.25393	0.25010
5	10		1.25374	0.25003
6	13		1.25359	0.25000
7	15		1.25349	0.25000
8	17	23.1	1.25340	0.24997
9	21		1.25323	0.24993
10	22	23.0	1.25312	0.24991

Average Ratio of Coils: 5.014005

3. **Calibration Data for Standard Thermometer.** See Part IV, Sec. 6.

Resistance at 0° C. (Extension Coil link in 25 ohm position.)
1. 3 April 1916.

Time Hrs.:Mins.	Resistance Ohms.
2:18	0.87280
2:19	0.87276
2:20	0.87275
2:21	0.87274
2:22	0.87277
2:24	0.87273
2:27	0.87263

Time Hrs.:Mins.	Resistance Ohms
2:29	0.87268
2:30	0.87259
2:31	0.87258
2:33	0.87258
2:34	0.87260

$R_0° = 0.87258$

2. 8 April 1916.

1:02	0.87262
1:04	0.87268
1:06	0.87263
1:08	0.87268
1:12	0.87253
1:18	0.87249
1:21	0.87249
1 24	0.87256
1:27	0.87246
:28	0.87248

$R_0° = 0.87248$

3. 8 April 1916.

10:28	0.87323
10:30	0.87324
10:31	0.87323
10:33	0.87323
10:36	0.87328
10:42	0.87330

$R_0°$ = Ice Heating, Measurement not used.

4. 8 April 1916.

12:00	0.87349
12:02	0.87349
12:04	0.87343
12:07	0.87356
12:12	0.87355

$R_0°$ = Ice Heating, Measurement not used.

5. 9 April 1916.

12:15	0.87467
12:16	0.87467

Time Hrs. :Mins.	Resistance Ohms
12:22	0.87465
12:25	0.87466
12:31	0.87466
2:48	0.87442

$R_0°$ = Ice Cooling, Measurement not used.

6. 9 April 1916.

3:21	0.87428
3:25	0.87430
3:35	0.87430
3:50	0.87430
3:56	0.87437

$R_0°$ = Ice Heating, Measurement not Used.

7. 10 April 1916.

3:46	0.87241
3:48	0.87239
3:53	0.87231
3:55	0.87231
3:58	0.87231
5:02	0.87242

$R_0° = 0.87231$

8. 10 April 1916.

5:30	0.87260
5:32	0.87259
5:37	0.87259
5:43	0.87263

$R_0° = 0.87259$

9. 10 April 1916.

6:02	0.87268
6:03	0.87265
6:05	0.87265
6:09	0.87266

$R_0° = 0.87265$

10. 10 April 1916.

7:59	0.87303
8:02	0.87303

Time Hrs.:Mins.	Resistance Ohms
8:04	0.87304
8:05	0.87303
8:21	0.87303

$R_0° = 87303$

Average Value of $R_0° = 0.87261$ ohms $\pm$ 0.00016 ohms.

Resistance at 100° C. and Evaluation of 9 ohm extension coil.

1. 5 April 1916.

Time Mins.	Position of Extension Coil.	Resistance Ohms	Barometer Inches	Temp. of Bar. 0° F.
0	25	10.90825	29.519	73.0
1	25	10.90829		
2	25	10.90828		
3	25	10.90841	29.521	73.0
5	25	10.90833	29.519	73.5
7	34	1.90607		
8	25	10.90835	29.519	74.0
10	34	1.90607		
11	25	10.90832		
12	34	1.90613	29.517	74.5
13	25	10.90837		
15	34	1.90614	29.519	74.5
16	25	10.90857		
17	34	1.90628	29.518	74.5

Barometer Instrumental Correction = + 0.023 inches.
R = 10.90835 at 99.532 °C.
Fundamental Interval = 10.08292 ohms.
9 ohm extension coil = 9.00211 ohms.

2. 8 April 1916.

0	25	10.90333	29.464	72.0
1	25	10.90343		
3	25	10.90361	29.463	72.0
4	25	10.90352		
6	25	10.90349		
7	25	10.90352		
9	25	10.90359	29.470	72.5

Time Mins.	Position of Extension Coil.	Resistance Ohms	Barometer Inches	Temp. of Bar. 0° F.
10	34	1.90139	29.470	72.5
12	25	10.90359	29.470	72.5
14	34	1.90141		
16	25	10.90371		
17	34	1.90144		
18	25	10.90371	29.468	72.0
19	34	1.90133		
21	25	10.90362		
22	34	1.90120		
23	25	10.90355		
24	34	1.90136	29.482	74.5

R = 10.90356 at 99.488° C.
Fundamental Interval = 10.08257 ohms.
9 ohm extension coil = 9.00220 ohms.

3. 10 April 1916.

0	25	10.90821		
1	25	10.90814	29.503	67.0
4	25	10.90824	29.506	67.0
5	34	1.90616	29.500	67.0
6	25	10.90818	29.496	68.0
8	25	10.90803	29.506	68.0
9	34	1.90586	29.498	68.0
10	25	10.90809		
11	34	1.90592		
12	25	10.90803	29.490	68.0
13	34	1.90592	29.490	68.0
15	34	1.90592	29.498	68.0
17	25	10.90825	29.506	68.0
20	34	1.90596	29.504	68.0
22	25	10.90796	29.500	68.0
23	34	1.90588	29.494	68.0
25	25	10.90812		

R = 10.90813 at 99.528 °C.
Fundamental Interval = 10.08311 ohms.
9 ohm extension coil = 9.00218 ohms.

4. 10 April 1916.

Time Mins.	Position of Extension Coil.	Resistance Ohms	Barometer Inches	Temp. of Bar. 0° F.
0	25	10.90748	29.481	67.0
1	34	1.90530	29.481	67.0
3	25	10.90742		
4	25	10.90715		
6	25	10.90684		
7	25	10.90674	29.470	67.0
8	25	10.90676		
9	25	10.90670	29.472	67.0
11	25	10.90670	29.474	67.0
12	25	10.90667		
13	25	10.90667	29.475	67.0
14	25	10.90665	29.472	67.5
15	34	1.90450		
17	25	10.90661	29.476	67.5
19	34	1.90455		

R = 10.90687 at 99.506 °C.
Fundamental Interval = 10.08407 ohms.
9 ohm extension coil = 9.00209 ohms.

Average Value of $R_{100°}$ = 10.95578 ohms ± 0.00050 ohms.
Average value of 9 ohms extension coil = 9.00214 ohms ± 0.00004 ohms.

Resistance at 218.0 °C. (Extension Coil Link in 34 ohm position.)

1. 6 April 1916.

Time Mins.	Resistance Ohms.	Barometer Inches	Bar. Temp. 0° F.
0	13.42348	29.732	72.5
1	13.42331	29.724	72.5
3	13.42323		
4	13.42322	29.726	72.5
6	13.42352		
7	13.42376		
9	13.42400	29.730	72.5
10	13.42405		
11	13.42429	29.734	72.5
12	13.42431		
14	13.42464	29.738	72.5

R = 13.42380 ohms at 217.58 °C.

2. 8 April 1916.

Time Mins.	Resistance Ohms	Barometer Inches	Bar. Temp. 0° F.
0	13.38990		
1	13.39001	29.483	73.5
2	13.39001	29.484	73.5
3	13.39035	29.484	73.5
4	13.39046	29.485	73.5
5	13.39102	29.485	74.0
6	13.39090	29.483	74.0
7	13.39115		
8	13.39136		
9	13.39175	29.490	74.0
11	13.39197	29.492	74.0
13	13.39219	29.490	74.0

Using first seven readings only.
$R = 13.39038$ ohms at 217.21 °C.

3. 8 April 1916.

0	13.39655		
1	13.39666	29.510	67.5
3	13.39693	29.510	67.5
4	13.39696	29.510	67.5
5	13.39705	29.512	67.5
6	13.39745	29.510	67.5
7	13.39743	29.508	67.5
8	13.39749	29.509	67.5
9	13.39773	29.512	67.5
10	13.39773	29.511	67.5
11	13.39811	29.522	67.5
12	13.39841	29.520	67.0
15	13.39861	29.520	67.0

Using first ten readings only.
$R = 13.39720$ ohms at 217.28 °C.

4. 8 April 1916.

0	13.39964		
1	13.39983		
2	13.39931	29.513	65.0
3	13.39849	29.510	65.0

Time Mins.	Resistance Ohms	Barometer Inches	Bar. Temp. 0° F.
4	13.39849	29.511	65.0
5	13.39890	29.510	65.0
6	13.39900	29.508	65.5
7	13.39893	29.508	65.5
8	13.39909	29.510	65.5
10	13.39938	29.524	65.5

$R = 13.39911$ ohms at 217.28 °C.

Computed values of δ_c:

1. 1.532
2. 1.488
3. 1.487
4. 1.479

The average of Nos. 2, 3, and 4 was taken as the value of δ_c.

$\delta_c = 1.485 \pm 0.004$

4. **Calibration Data for Observing Thermometer.** See Part IV, Sec. 7.

Column 2 gives the resistance of the Standard Thermometer, and Column 3 gives the resistance of the Observing Thermometer, the units being ohms. The Extension Coil Link was in the 25 ohm position. The readings in Column 3 were not made simultaneously with those in Column 2 but were made as soon after as the bridge could be reset.

1. 6 May 1916. Oil Bath at 63.2 °C.

Time Mins.	Standard Thermometer Ohms	Observing Thermometer Ohms
0	7.27945	5.01562
2	7.27955	5.01578
4	7.27923	5.01575
7	7.27937	5.01561
9	7.27917	5.01566
12	7.27970	5.01550
14	7.27952	5.01572
17	7.27911	5.01563
19	7.28018	5.01562
22	7.27973	5.01583
Averages	7.27950	5.01567

2. 7 May 1916. Oil Bath at 63.2 °C.

Time Mins.		Standing Thermometer Ohms	Observing Thermometer Ohms
0		7.27958	5.01609
2		7.27932	5.01589
4		7.28011	5.01593
6		7.27958	5.01605
9		7.27935	5.01592
11		7.27991	5.01594
13		7.27929	5.01604
16		7.27959	5.01580
	Averages	7.27959	5.01596

3. 7 May 1916. Oil Bath at 114.8 °C.

0		12.42866	8.49468
2		12.42795	8.49478
5		12.42763	8.49459
7		12.42819	8.49466
9		12.42813	8.49460
11		12.42898	8.49475
13		12.42861	8.49488
16		12.42773	8.49488
18		12.42888	8.49463
21		12.42876	8.49500
	Averages	12.42835	8.49475

4. 7 May 1916. Oil Bath at 25.1 °C.

0		3.43125	2.41286
2		3.43121	2.41288
4		3.43135	2.41277
6		3.43155	2.41290
9		3.43159	2.41299
11		3.43172	2.41306
14		3.43188	2.41306
17		3.43165	2.41313
19		3.43153	2.41318
21		3.43136	2.41309
	Averages	3.43151	2.41299

5. 8 May 1916. Oil Bath at 24.3 °C.

Time Mins.		Standing Thermometer Ohms	Observing Thermometer Ohms
0		3.34948	2.35780
2		3.34917	2.35761
4		3.34906	2.35738
5		3.34913	2.35728
8		3.34942	2.35718
10		3.34946	2.35718
11		3.34957	2.35723
13		3.34954	2.35731
15		3.34967	2.35739
17		3.34997	2.35742
	Averages	3.34945	2.35738

6. 8 May 1916. Oil Bath at 62.7 °C.

0		7.23368	4.98518
2		7.23407	4.98496
5		7.23430	4.98506
7		7.23404	4.98498
11		7.23357	4.98495
14		7.23414	4.98490
18		7.23410	4.98494
20		7.23368	4.98478
24		7.23336	4.98456
26		7.23420	4.98473
	Averages	7.23391	4.98490

7. 9 May 1916. Oil Bath at 113.0 °C.

0		12.24023	8.36802
3		12.24053	8.36785
6		12.24212	8.36840
8		12.24130	8.36870
11		12.24036	8.36805
13		12.24197	8.36855
15		12.24086	8.36840
17		12.24203	8.36842
19		12.24084	8.36836
22		12.24127	8.36799
	Averages	12.24115	8.36827

Average Results: $R_{100°} - R_{0°} = 6.81925$ ohms.
$R_{0°} = 0.68084$ ohms.
$\delta_c = 1.600$

5. **Mass of Ammonia.** See Part IV, Sec. 8.

1. 3 April 1916. 8:20 P. M.

Apparent Mass of Container Empty	1163.6746 grams.
Temperature in Balance Case	20.4 °C.
Barometer	29.431 inches.
Temperature of Barometer	68.0 °F.

2. 3 April 1916. 9:08 P.M.

Apparent Mass of Container Empty	1163.6741 grams.
Temperature in Balance Case	19.8 °C.
Barometer	29.412 inches.
Temperature of Barometer	67.0 °F.

3. 3 April 1916. 10:50 P. M.

Apparent Mass of Container Empty	1163.6720 grams.
Temperature in Balance Case	18.7 °C.
Barometer	29.400 inches.
Temperature of Barometer	65.0 °F.

Inside volume of container (see Part V, Sec. 6) approx. 273 cc.
Volume of steel of container, approx. 149 cc.
Weights, brass; small weights, quartz.
Fortin Barometer, brass scale; instrumental correction + 0.023 in.
Reduction to Vacuo:

1. 1164.0094 grams.
2. 1164.0097 grams.
3. 1164.0088 grams.

Average 1164.0093 = True Mass of Container Empty.

---

1. 4 April 1916. 9:10 P. M.

Apparent Mass of Container Filled with NH_3	1266.3938 grams.
Temperature in Balance Case	21.2 °C.
Barometer	29.530 inches.
Temperature of Barometer	71.0 °F.

2. 4 April 1916. 10:15 P. M.

Apparent Mass of Container Filled with NH_3	1266.3918 grams.
Temperature in Balance Case	21.2 °C.
Barometer	29.576 inches.
Temperature of Barometer	70.5 °F.

3. 4 April 1916. 11:00 P. M.

Apparent Mass of Container Filled with NH_3	1266.3905 grams.
Temperature in Balance Case	21.2 °C.
Barometer	29.576 inches.
Temperature of Barometer	70.5 °F.

4. 5 April 1916. 11:30 A. M.

Apparent Mass of Container Filled with NH_3	1266.3883 grams.
Temperature in Balance Case	20.5 °C.
Barometer	29.560 inches.
Temperature of Barometer	71.0 °F.

5. 5 April 1916. 2:20 P. M.

Apparent Mass of Container Filled with NH_3	1266.3902 grams.
Temperature in Balance Case	21.4 °C.
Barometer	29.518 inches.
Temperature of Barometer	72.0 °F.

6. 5 April 1916. 3:00 P. M.

Apparent Mass of Container Filled with NH_3	1266.3905 grams.
Temperature in Balance Case	21.6 °C.
Barometer	29.516 inches.
Temperature of Barometer	73.0 °F.

Reduction to Vacuo:

1. 1266.7136 grams.
2. 1266.7121 grams.
3. 1266.7108 grams.
4. 1266.7095 grams.
5. 1266.7097 grams.
6. 1266.7100 grams.

Average 1266.7110 grams = True Mass of Container filled with NH_3.

Mass of Ammonia enclosed in container = 102.7017 grams.

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6. **Volume of Ammonia Container.**

1. 31 March 1916.

Apparent Mass of Container Empty	1163.6765 grams.
True Mass of Container Empty (in Vacuo)	1164.0175 grams.
Apparent Mass of Contianer filled with distilled water at the temperature 22.5° C.	1436.7602 grams.
True Mass of Container filled (in Vacuo)	1437.0619 grams.

$V = 273.6779$ cc.

2. 1 April 1916.

Apparent Mass of Container Empty	1163.7653 grams.
True Mass of Container Empty (in Vacuo)	1164.1063 grams.
Apparent Mass of Container filled with distilled water at the temperature 23.5 °C.	1435.7703 grams.
True Mass of Container filled (in Vacuo)	1436.0718 grams.

$V = 272.6615$ cc.

3. 1 April 1916.

Apparent Mass of Container Empty	1163.8013 grams.
True Mass of Container Empty (in Vacuo)	1164.1423 grams.
Apparent Mass of Container filled with distilled water at the temperature 21.5 °C.	1436.5200 grams.
True Mass of Container filled (in Vacuo)	1436.8217 grams.

$V = 272.9766$ cc.

Average value of $V = 273.11$ cc. $\pm$ 0.38 cc.

$v = 2.6593$ ccs./ gram.

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4. 11 July 1919

Apparent Mass of Container Empty	1167.6036 grams.
True Mass of Container empty (in Vacuo)	1167.9352 grams.
Apparent Mass of Container filled with distilled water at the temperature 26.60 °C.	1440.8404 grams.
True Mass of Container filled (in Vacuo)	1441.1329 grams.
Apparent Mass of Container filled with distilled water at the temperature 78.0 °C.	1434.3345 grams.

True Mass of Container filled (in Vacuo)	1434.6228 grams.
Volume of Container at 26.60 °C.	274.113 cc.
Volume of Container at 78.0° C.	274.054 cc.

This change in V is within the experimental error and the conclusion is that δV is negligible.

7. E. M. F. of Standard Cell.

Certified by the U. S. National Bureau of Standards, Oct. 18, 1915.

"Unsaturated Weston Standard Cell #1458.

Electromotive Force at 22.1° C. = 1.0180_8 international volts. The above value is correct to 0.01 percent."

8. Resistance of Standard Ohm.

Certified by the Leeds & Northrup Co. Oct. 11, 1915.

"No. 4020 Standard Resistance, Serial #27659

1.000_3 International Ohms at 20° C.

Its temperature coefficient between 15° and 30° is

0.000007 per degree Centigrade.

The error in the above comparison is not greater than 1/100th%."

9. Quality of Ammonia Used.

The ammonia used in these experiments was commercial anhydrous ammonia, NH_3, obtained from Armour & Co., Chicago, in February 1916, and shipped in a fifty pound drum.

As to the purity of the ammonia, Mr. J. R. Powell, Chief Chemist, Armour Ammonia Works, may be quoted:

"As to the impurities that might be expected present, there will probably be traces of water, carbon dioxide, and possibly methyl cyanide, but the total of these impurities should not be over one or two hundredths of one per cent. Likewise there may be bare traces of foreign gas dissolved in the ammonia, these gases being principally air. Anhydrous ammonia, as manufactured today is practically a chemically pure product."

10. Data on Method of Filling Container with Ammonia.

The ammonia container was connected to the ammonia tank by means of a copper pipe of 5 mm. outside diameter. In this copper pipe was inserted a glass Tee, the branch of which led to a vacuum pump equipped with a gauge. The copper-glass joints were made with Khotinsky cement.

The ammonia valve was opened slightly, before connecting up, to clear the opening of any foreign matter which might be present in

the valve, and then closed. The line was pumped down to a pressure of about 2 mm. of mercury, and then ammonia was admitted to the system and allowed to stand for about twenty minutes. The line was again pumped down to about 2 mm. of mercury and the glass tube leading to the pump sealed off. A thermos bottle had been previously filled with solid carbon dioxide and the ammonia container was now immersed in this CO_2 snow and allowed to cool for fifteen minutes. The ammonia valve was again opened and ammonia admitted to the system until no more flowed. The pipe line was then unscrewed and the filling plug screwed in place, there being no appreciable escape of ammonia from the container during this operation.

After the container had warmed up to room temperature it was weighed, and the ammonia allowed to escape until the mass of ammonia in the container had been reduced to slightly over 100 grams. The exact mass of ammonia has been given above.

It was desired to use as large a mass of ammonia as possible in the container but to so load it that all the vapor would not be condensed at the highest temperature contemplated for these measurements. Using Keyes and Brownlee's data on the specific volume of the liquid, it was determined that with a filling of 100 grams the vapor would be condensed at a temperature of about 123° C. which put an upper limit on the measurements, for that particular filling. It was originally intended to let out about fifty grams of ammonia, after these measurements had been made up to 123° C. and go on up to the critical point, 132.9° C. but time was not available to do this.

11. **Data on Calorimetric Lag.**

In Part IV, Section 4, the various calorimetric lags are discussed. With the assumptions and methods there outlined, the following data was obtained from the observed calorimeter curves.

The length of time taken for the mercury in the calorimeter to equalize its differences of temperature after the heater was switched off, was, on the average, about 12 secs., varying from 10 to 14 secs. The rise of temperature of the mercury after the heater was switched off was, on the average, about 0.00030 ohms on the observing thermometer, or about 0°.0044 C. The time taken to equalize the differences of temperature in the entire calorimeter after the heater was switched off, was different for the ammonia measurements and for the calibration measurements, averaging 11 minutes for the former, and 15 minutes for the latter. In the case of the ammonia measurements, the temperature of the mercury at the instant the heater was switched off, was, on the average, about 0°.046 C. hotter than the equalized

temperature of the calorimeter at the same instant. In the case of the calibration measurements, it was 0°.12 C. hotter than the equalized temperature.

12. **Data on Accuracy of Chronograph.**

The chronograph was controlled by a laboratory pendulum clock which was compared with standard time for several days before the final measurements were made, and was found to be correct to within a few seconds a day.

The distance between second marks made by the pen on the chronograph sheet, were approximately 1 cm., and the record marks could be located to within $\frac{1}{2}$ mm., giving an error at each end of the time interval of not more than 1/20th sec. The time record was made automatically by throwing the heater switch on and off.

13. **Data on Regulation of Constant Temperature Bath.**

The thermostat maintained the bath temperature constant within a range of 0°.02 C. and in most measurements, within a range of 0°.01 C. In Ammonia Measurement 9, the bath got out of control and the temperature shows a variation of 0°.07 C. This variation is in a direction to give too high a value of $\frac{\delta H_1}{\delta \theta}$.

VI. Experimental Results.

1. **Computed and Faired Values of Heat Capacity of Apparatus:**

(a) When Filled with Ammonia. (b) When Empty.

Equations (6) and (18) are the laboratory equations by which the values of δH and $\delta \theta$ are computed. Equation (13) gives the value of $k/2$.

These experimental results are summarized in the following table, whose explanation is as follows:

Column 1. Number of the measurement, for reference to the tables from which the values were computed.

Column 2. Temperature of the measurement, in °C., taken as the temperature equivalent to R_m for that measurement.

Column 3. Experimental values of $\frac{\delta H_1}{\delta \theta}$ and $\frac{\delta H_2}{\delta \theta}$, in Joules /°C., computed by equations (6) and (18) from the tabulated data.

Column 4. Faired values of $\frac{\delta H_1}{\delta \theta}$ and $\frac{\delta H_2}{\delta \theta}$, obtained by drawing the best representative curve through the data in Column 3, plotted as a function of temperatures given in Column 2. Units: Joules /°C.

Column 5. Percentage deviation of the values of Column 3, from those of Column 4.

Column 6. Values of $k/2$ in minutes $^{-1}$.

EXPERIMENTAL RESULTS. TABLE I.

No.	θ_m	Ammonia Measurements. $\frac{\delta H_1}{\delta \theta}$ Observed.	$\frac{\delta H_1}{\delta \theta}$ Curve.	% Diff.	$k/2$
1	32.9	2135.8	2136.0	0.00	0.00271
2	39.6	2174.4	2151.0	+1.09	0.00203
3	40.3	2125.4	2153.0	−1.28	0.00211
4	51.9	2169.0	2179.0	−0.46	0.00211
5	62.9	2212.6	2206.0	+0.30	0.00225
6	72.7	2245.4	2231.0	+0.65	0.00262
7	83.2	2265.5	2258.7	+0.30	0.00247
8	92.8	2275.3	2287.5	−0.53	0.00291
9	102.9	2332.2	2331.0	+0.09	0.00214
10	102.9	2327.9	2331.0	−0.13	0.00266
11	113.0	2396.3	2391.0	+0.22	0.00219
12	122.5	2469.9	2478.7	−0.35	0.00244
		Calibration Measurements.			
		$\frac{\delta H_2}{\delta \theta}$	$\frac{\delta H_2}{\delta \theta}$		
1	23.3	1604.2	1602.9	+0.08	0.00288
2	26.9	1641.9	1606.8	+2.18	0.00170
3	39.8	1617.3	1619.0	−0.10	0.00253
4	39.8	1618.8	1619.0	0.00	0.00286
5	40.2	1625.5	1619.5	+0.37	0.00300
6	40.2	1616.6	1619.5	−0.18	0.00265
7	40.2	1616.9	1619.5	−0.16	0.00276
8	60.9	1635.2	1641.5	−0.38	0.00395
9	79.9	1691.6	1661.0	+1.84	0.00252
10	82.7	1675.9	1664.0	+0.71	0.00359
11	100.6	1675.5	1684.2	−0.52	0.00362
12	121.9	1708.7	1708.7	0.00	0.00406

Average Deviation of $\frac{\delta H_1}{\delta \theta}$ without regard to sign, = 0.45%.

Average Deviation of $\frac{\delta H_2}{\delta \theta}$ without regard to sign = 0.54%.

Figure 8 is a plot of the values of the heat capacity of the apparatus both full of ammonia and empty, and shows the computed values and the faired curves drawn through these points.

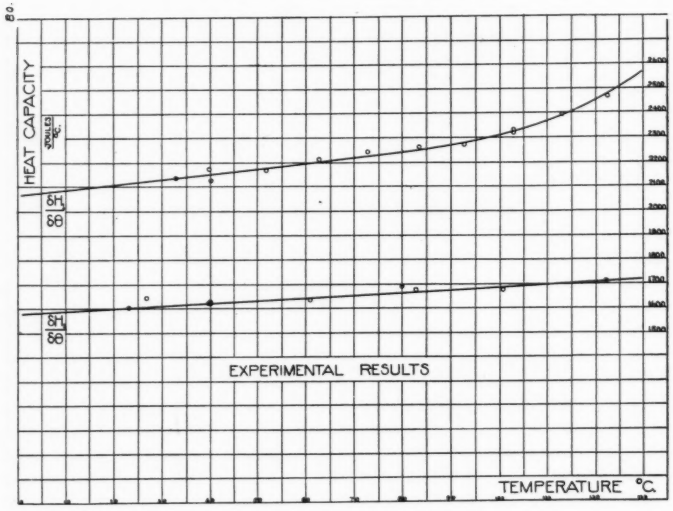

FIGURE 8.

2. **Specific Heat at Constant Specific Volume of Mixture of Liquid and Vapor.**

The specific heat of the mixture of liquid and vapor at the constant specific volume 2.6593 ccs./gram, was computed from Equation 2, using the faired values of $\frac{\delta H_1}{\delta \theta}$ and $\frac{\delta H_2}{\delta \theta}$ given in Table I and the value of M previously given.

These values are given for every five degrees Centigrade in the following table.

EXPERIMENTAL RESULTS. TABLE II.

θ in °C.	$c_{v_{2\cdot6593}}$ in Joules/Gm.-degree.	θ in °C.	$c_{v_{2\cdot6593}}$ in Joules/Gm.-degree.
30	5.075	80	5.737
35	5.132	85	5.815
40	5.190	90	5.907
45	5.251	95	6.021
50	5.313	100	6.165
55	5.378	105	6.344
60	5.446	110	6.570
65	5.515	115	6.878
70	5.587	120	7.262
75	5.660	125	7.802

These values are plotted in Figure 9.

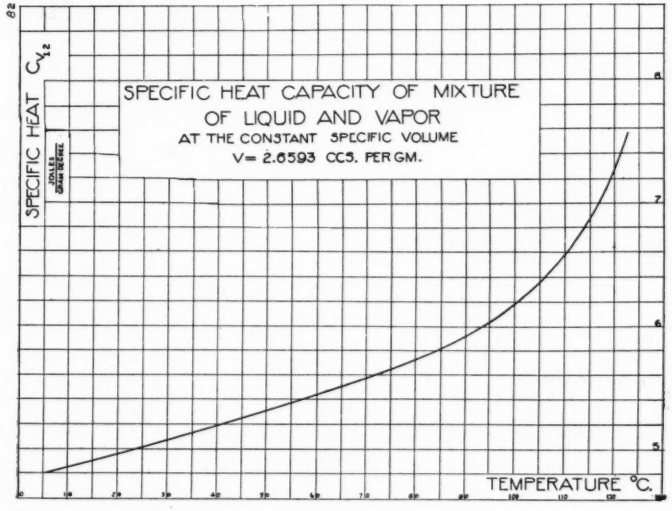

FIGURE 9.

VII. The Saturation Specific Heat of the Liquid c_{s_2}, and the Saturation Specific Heat of the Vapor c_{s_1}, in Terms of $c_{v_{12}}$.

1. Derivation of Equations.

Let the total mass of substance in the liquid container be M, and since this is constant

$$\delta M = 0 \tag{21}$$

Let M_1 and M_2 be the masses of the vapor and liquid phases respectively. These are variables and functions of the temperature but related by the equation

$$M_1 + M_2 = M \tag{22}$$

Let V = the volume of the container, a constant,
and call $V/M = v$.
Let v_1 = the specific volume of the saturated vapor, and
v_2 = the specific volume of the saturated liquid.
Then

$$v_1 M_1 + v_2 M_2 = V = Mv \tag{23}$$

If $\delta\theta$ = the temperature change of the substance due to the heat δQ added to that substance, and
L = the total heat of vaporization of the liquid phase, then

$$\delta Q = c_{s_2} M_2 \, \delta\theta + c_{s_1} M_1 \, \delta\theta + L \delta M_1 \tag{24}$$

By means of (21), (22) and (23), M_2, M_1, and δM_1, are eliminated from (24). Rearranging terms after this elimination,

$$\frac{1}{M}\frac{\delta Q}{\delta\theta} = c_{s_2}\frac{v_1 - v}{v_1 - v_2} + c_{s_1}\frac{v - v_2}{v_1 - v_2} - \frac{L}{v_1 - v_2}\left\{\left(1 - \frac{v - v_2}{v_1 - v_2}\right)\frac{\delta v_2}{\delta\theta} - \left(\frac{v - v_2}{v_1 - v_2}\right)\left(-\frac{\delta v_1}{\delta\theta}\right)\right\} \tag{25}$$

By Equation 1

$$c_{v_{12}} = \frac{1}{M}\frac{\delta Q}{\delta\theta} \tag{1}$$

and a general thermodynamic relation [15] gives

$$c_{s_1} = c_{s_2} - \left(\frac{L}{T} - \frac{dL}{dT}\right) \tag{26}$$

---

15 Reference 3, p.

where T denotes absolute temperature, as distinguished from θ which is used to denote the usual Centigrade scale.
Substituting (1) and (26) in (25) and solving for c_{s_2},

$$c_{s_2} = c_{v_{12}} + \left(\frac{v - v_2}{v_1 - v_2}\right)\left(\frac{L}{T} - \frac{dL}{dT}\right) - \frac{L}{v_1 - v_2}\left\{\left(\frac{v - v_2}{v_1 - v_2}\right)\left(-\frac{\delta v_1}{\delta\theta}\right) - \left(1 - \frac{v - v_2}{v_1 - v_2}\right)\frac{\delta v_2}{\delta\theta}\right\} \quad (27)$$

By use of Equations (26) and (27), the specific heats along the boundary line of the liquid vapor region shown in Figure 2, can be computed, when the experimentally determined values of $c_{v_{12}}$ (Table II), and the thermodynamic quantities, L, v_1 and v_2, are given as functions of the temperature.

In Equation 27, v denotes the specific volume at which $c_{v_{12}}$ was measured. But from values of $c_{v_{12}}$ as a function of the temperature at some one particular specific volume, the values of $c_{v_{12}}$ at any other specific volume can be computed. Let the volume at which the measurements are made be denoted v_a instead of v, and let the specific heat at this specific volume be c_{va} where the subscripts $_1$ and $_2$ are understood. Similarly, let c_{vb} be the specific heat of the liquid-vapor mixture at the specific volume v_b. To obtain an equation connecting c_{v_a} and c_{v_b}, write Equation 27 twice, once using c_{v_a} and v_a, and again using c_{vb} and v_b. Subtracting these two and rearranging

$$c_{v_a} - c_{v_b} = \left(\frac{v_b - v_a}{v_1 - v_2}\right)\left\{\frac{L}{T} - \frac{dL}{dT} - \frac{L}{v_1 - v_2}\left(-\frac{\delta v_1}{\delta\theta} + \frac{\delta v_2}{\delta\theta}\right)\right\} \quad (28)$$

Further, the specific heat along any path whatsoever,[16] may be written

$$c = c_v + T\left(\frac{\partial p}{\partial T}\right)_v \frac{dv}{dT} \quad (29)$$

where p is the pressure and $\frac{dv}{dT}$ depends on the path.

These equations, (26), (27), (28) and (29), show that the specific heat along any path in the liquid-vapor region, and along the boundary of that region, may be computed from values of the specific heat along some one constant specific volume line in that region. Such

16 Reference (3) p. 5. Modification of Eq. 10.

values of c_v at the specific volume 2.6593 ccs./gram, have been given in Table II. over the temperature range 30° C. to 125° C.

2. **Keyes-Brownlee Data for Ammonia.**

To compute the numerical values of c_{s_2} and c_{s_1} from these values of c_v, by means of (26) and (27) the data of Keyes and Brownlee is used.

For the heat of vaporization, Keyes,[17] using 1 cal.: = 4.182 Joules, gives

$$\log_{10}L = 1.56817 - 2.822\cdot10^{-5}\,(406.0 - T) + 0.43387\,\log_{10}(406.0 - T) \qquad (30)$$

where L is in calories per gram; and T is in degrees absolute on the Centigrade scale.

From this equation we obtain

$$\left(\frac{dL}{dT} - \frac{L}{T}\right) = \mathrm{L}\left\{6.49788\cdot10^{-5} - \frac{0.43387}{406.0 - T} - \frac{1}{T}\right\} \qquad (31)$$

In the following table are given the values of L and of $\left(\frac{L}{T} - \frac{dL}{dT}\right)$ for each 10°C. computed from equations (30) and (31). The first column gives the temperature in degrees Centigrade; the units of column two and three, are Joules per gram, and Joules per gram-degree, respectively.

θ	L	$\frac{L}{T} - \frac{dL}{dT}$
0	1279.8	8.7807
10	1237.9	8.6616
20	1194.2	8.5863
30	1147.8	8.5511
40	1098.7	8.5688
50	1046.4	8.6464
60	990.3	8.8018
70	929.5	9.0608
80	862.8	9.4632
90	788.3	10.0918
100	703.0	11.1088
110	601.0	12.9161
120	468.9	16.9329
130	245.5	36.9541

17 Reference (3) p. 24. Eq. 34.

The specific volume of the vapor, v_1, was obtained by solving Keyes' equation of state for ammonia, simultaneously with the equation for the vapor pressure as a function of the temperature. The equation of state is:[18]

$$p = \frac{R_k T}{v - \delta_k} - \frac{a}{(v - l)^2} \tag{32}$$

$$R_k = 4.8177 \qquad \log_{10}\delta_k = 0.98130 - \frac{3.08}{v}$$

$$a = 34610.1 \qquad l = -1.173$$

p in atmos. T in degrees absolute on Centigrade scale.
v in ccs./gram.
The vapor pressure equation[19] is:

$$\log_{10}p = -1969.65\ T^{-1} + 16.19785 - 0.0323858\ T + 5.4131\cdot10^{-5}\ T^2 - 3.2715\cdot10^{-8}\ T^3 \tag{33}$$

where p is pressure in mm. of mercury, and T temperature on the absolute scale in degrees centigrade.

The method of solving these two equations is to substitute values of v in (32) thus reducing (32) to an equation giving p as a linear function of T for any given volume. Equation 33 was solved for p for each 5° C. and these values plotted to a large scale. The straight lines connecting p and T were then drawn on the same diagram, and from the point of intersection of each line with the curve, the values of T were read off. Since each straight line corresponds to a value of v, this process gives v_1 as a function of T and therefore as a function of θ.

The following tables give the computed values of p and v_1 as a function of θ. θ is in °C., p in atmos. and v_1 in ccs./gm.

θ	p	θ	p
10	6.128	75	36.697
15	7.256	80	40.937
20	8.535	85	45.567
25	9.979	90	50.553
30	11.605	95	55.973
35	13.419	100	61.797
40	15.438	105	68.053

18 Reference (3) p. 20. Eq. 33.
19 Reference (3) p. 13. Eq. 30.

θ	p	θ	p
45	17.681	110	74.782
50	20.164	115	82.036
55	22.901	120	89.753
60	25.897	125	98.061
65	29.186	130	106.883
70	32.778	132.9	112.281

v_1	θ	v_1	θ
16	104.33	104	32.03
18	99.76	115	28.64
20	95.50	126	25.66
30	78.86	137	22.79
40	67.39	148	20.24
51	57.99	160	17.80
62	50.67	172	15.48
72	45.21	184	13.39
82	40.45	196	11.31
93	35.92	208	9.73

The equation of state (32) with the constants there given does not hold very far beyond 100° C., so that values of the saturation specific heats cannot be computed in the range 100° C. — 125° C., until further experimental data are available.

The following empirical equation was set up by the writer to represent v_1 as a function of θ,

$$v_1 = 338.990 - 172.7327\,\theta + 46.2976\,\theta^2 - 7.6262\,\theta^3 + 0.73653\,\theta^4 - 0.035417\,\theta^5 + 0.0005278\,\theta^6 \qquad (34)$$

This equation readily yields the values of $\frac{dv_1}{d\theta}$,[20] required by Equation 27. The following table gives $\left(-\frac{dv_1}{d\theta}\right)$ in ccs./gm.-degrees, for each 10° C. as computed from Equation 34.

---

20 The quantities $\frac{\delta v_1}{\delta\theta}$ and $\frac{\delta v_2}{\delta\theta}$ are here replaced by the differential coefficients $\frac{dv_1}{d\theta}$ and $\frac{dv_2}{d\theta}$, the error introduced being negligible.

θ	$-\frac{dv_1}{d\theta}$
0	9.6202
10	6.6829
20	4.6430
30	3.2561
40	2.3255
50	1.6988
60	1.2645
70	0.9487
80	0.7120
90	0.5456
100	0.4687

Keyes gives a table of values of the specific volume of the liquid,[21] v_2, at various temperatures as shown in the table below; θ in °C. and v_2 in ccs./gram.

θ	v_2
0	1.5657
20	1.6387
40	1.7256
60	1.8331
80	1.9747
100	2.1836

The following empirical equation was set up by the writer to represent v_2 as a function of θ.

$$v_2 = 1.49380 + 0.079723\tau - 0.014021\,\tau^2 + 0.0074209\tau^3 - 0.00132917\,\tau^4 + 0.0001075\,\tau^5$$
$$\text{where } \tau = (\theta/20 + 1) \qquad (35)$$

By differentiation, the values of $\frac{dv_2}{d\theta}$ are obtained. These values of $\frac{dv_2}{d\theta}$ in ccs./gram-degree for each 10° C. as computed from (35) are given below.

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21 Reference (3) p. 15.

θ	$\frac{dv_2}{d\theta}$
0	0.002458
10	0.003626
20	0.003938
30	0.004334
40	0.004797
50	0.005350
60	0.006055
70	0.007014
80	0.008372
90	0.010311
100	0.013056

All of the quantities occurring in the right hand members of Equations (26) and (27) are now computed, and the values of c_{s_2} and c_{s_1} may be obtained by substitution in those two equations.

3. **Computed Values of the Saturation Specific Heats.**

Table III below, gives the values of the saturation specific heats for each 5° C. from 30° C. to 100° C. The first column gives the

TABLE III.

θ	$c_{v_{2\cdot 6593}}$	Corr. Term	c_{s_2}	c_{s_1}
30	5.075	−0.187	4.888	−3.663
35	5.132		4.937	−3.616
40	5.190	−0.199	4.991	−3.578
45	5.251		5.048	−3.550
50	5.313	−0.202	5.111	−3.535
55	5.378		5.179	−3.534
60	5.446	−0.194	5.252	−3.550
65	5.515		5.335	−3.583
70	5.587	−0.159	5.428	−3.633
75	5.660		5.538	−3.703
80	5.737	−0.072	5.665	−3.798
85	5.815		5.816	−3.930
90	5.907	+0.079	5.986	−4.106
95	6.021		6.181	−4.342
100	6.165	+0.268	6.433	−4.676

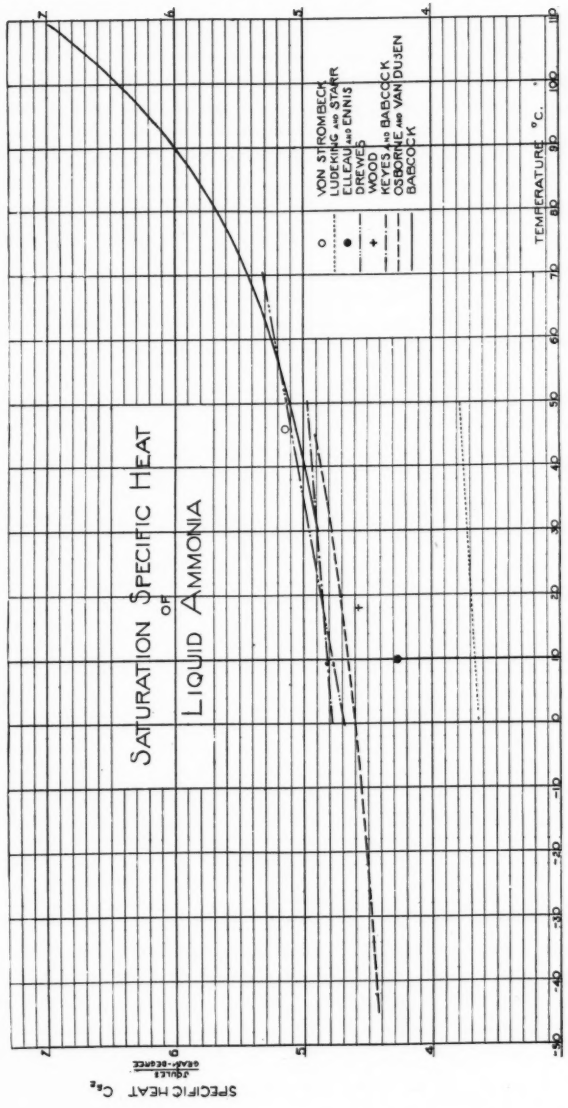
SATURATION SPECIFIC HEAT
OF
LIQUID AMMONIA
SPECIFIC HEAT C_s
JOULES / GRAM-DEGREE
TEMPERATURE °C.
VON STROMBECK
LUDEKING AND STARR
DIETERICI AND ENNIS
REGNAULT
WOOD
KEYES AND BABCOCK
OSBORNE AND VAN DUSEN
BABCOCK

FIGURE 10.

temperature in °C. and the second, c_v from Table II. In the third column, for every 10° C. is given the correction term to be added to c_v to give c_{s_2}. The fourth column gives c_{s_2} and the fifth gives c_{s_1}, whose values, it will be noted, are negative. All of the specific heats are expressed in Joules per gram degree. The values of the saturation specific heats given for 35°, 45°, 55°, etc., were obtained by interpolation, not computed.

The saturation specific heat of the liquid is shown by the heavy curve in Figure 10, and the saturation specific heat of the vapor is shown in Figure 11.

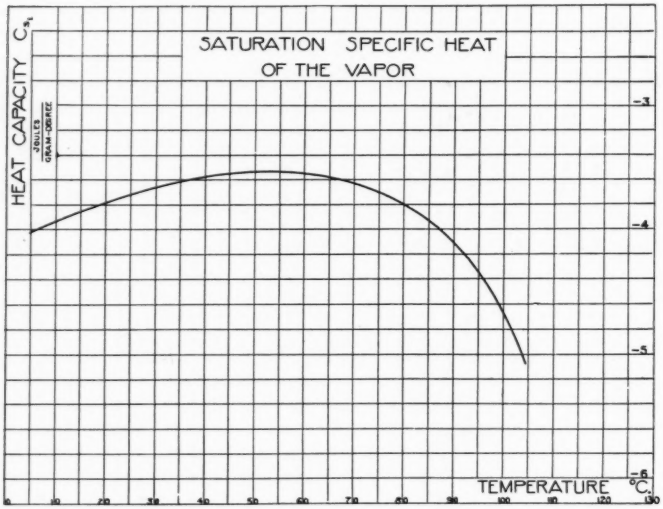

FIGURE 11.

4. Comparison with Previous Results.

Osborne and Van Dusen,[22] in their recent work, have discussed briefly the measurements of the specific heat of ammonia made previously to their own investigation. There is little to add to this except

22 Osborne & Van Dusen, Bull. Bur. of Standards, **14**, p. 397.

perhaps to mention a little more in detail the work of Drewes, reported by Dieterici.[23]

Drewes used the Bunsen Ice Calorimeter in the range 0°–70° C. He placed 0.5 grams of ammonia in a glass vessel whose volume was 1.2 cc. His results were expressed in terms of a calorie which appears to have the value 4.187 Joules. He assumed that the specific heat at constant volume was a linear function of the temperature, and gives the following equation for c_v.

$$c_v = 1.118 + 0.00208\,\theta \qquad 0° < \theta < 70° \tag{36}$$

where c_v is expressed in calories, and θ is in degrees C. Dieterici corrects only for the external work of liquid expansion in computing the saturation specific heat of the liquid, and gives the following equation for c_{s_2}:[24]

$$c_{s_2} = 1.118 + 0.00220\,\theta \qquad 0° < \theta < 70° \tag{37}$$

Dieterici gives only the approximate values of the volume of the container and the mass of ammonia enclosed therein, so it is not possible to apply Equation (27) to his equation for c_v. The specific volume at which his measurements were carried out was approximately 2.4 ccs./gram and hence the correction for the heat capacity of the vapor, the heat of vaporization, and the expansion of the liquid would appear to make his c_{s_2} *less* than c_v in the temperature region in which he operated, rather than larger, as he states, so that it is probable that his quoted values of c_{s_2} are too high, though how much too high it is not possible to determine.

The most accurate measurements of the specific heat of ammonia

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23 Dieterici, Zeit. f. d. Gesamte Kalte-Industrie. (1904), pp. 21, 47.

24 The values given for the specific heat of ammonia by Landolt & Bornstein, Physikalisch-Chemische Tabellen, 1905 Edition, are as follows:

θ in °C.	c in cal./gm.-degree
0	0.876
10	1.140
20	1.190
30	1.218
40	1.231
50	1.239
60	1.240
70	1.233

These values do not appear in the article by Dieterici, Reference 22, and the writer has no explanation for their appearance in the Tabellen.

which have yet appeared are those of Osborne and Van Dusen.[25] Using an aneroid calorimeter of special construction, the specific heat both at constant volume and at constant pressure was determined in the temperature region which is most useful in the refrigeration industry, − 45° C. to + 45° C.

Especial attention was paid to the elimination of heat transfer to the surroundings.

The final results of their measurements are expressed by the equation,

$$c_{s_2} = 3.1365 - 0.00057\,\theta + \frac{16.842}{(133-\theta)^{\frac{1}{2}}} \qquad (38)$$

where θ is in degrees C., and the saturation specific heat of the liquid is in Joules per gram degree C.

These experimenters put the precision of their results at 1 part in 1000.

The work of the present paper overlaps by about 15° the range of Osborne and Van Dusen's measurements, and in this overlapping region, differs from their results by about two and a quarter per cent. The difference between the values of v_1, v_2, and L, used by Osborne and Van Dusen, and the writer, is too slight to account for the difference in the saturation specific heats.

In Table IV. are given the values of the saturation specific heat of liquid ammonia, expressed in Joules per gram degree, for comparison. Figure 10 shows graphically the various reported values of the saturation specific heat of the liquid.

VIII. Critical Survey.

The experimental method and apparatus described in this paper were designed for the measurement of the specific heat of ammonia as a function of temperature up to the critical point. From the outset, the conditions met with at the higher temperatures determined the design of the apparatus and placed a limit on the accuracy attainable. At the highest temperature reached, 125° C., the pressure in the container was about 100 atmospheres, which necessitated a rather massive container, which in turn gave rise to temperature lag difficulties already discussed. Furthermore, to obtain measurements of the specific heat in the region near the critical temperature, where it is

[25] Osborne & Van Dusen, Bull. Bur. of Standards, **14**, p. 397.

TABLE IV.

COMPARISON OF VALUES OF THE SATURATION SPECIFIC HEAT OF THE LIQUID.

θ	Von Strombeck 1890	Ludeking and Starr 1893	Elleau and Ennis 1898	Drewes 1904	Wood 1912	Keyes and Babcock 1912	Osborne and Van Dusen 1916	Babcock 1916
−40	.....	.....	.....	.....	.....	.....	4.442	.....
−30	.....	.....	.....	.....	.....	.....	4.476	.....
−20	.....	.....	.....	.....	.....	.....	4.509	.....
−10	.....	.....	.....	.....	.....	.....	4.551	.....
0	.....	.....	.....	4.681	.....	.....	4.597	.....
+10	.....	.....	4.270	4.773	.....	4.818	4.651	.....
+13	.....	3.672	.....	4.799	.....	.....	4.668	.....
+18	.....	.....	.....	4.844	4.576	.....	4.698	.....
+20	.....	.....	.....	4.861	.....	.....	4.710	.....
+30	.....	.....	.....	4.945	.....	.....	4.777	4.888
+35	.....	.....	.....	4.991	.....	4.901	4.819	4.939
+36	.....	3.739	.....	5.000	.....	.....	4.827	4.949
+40	.....	.....	.....	5.037	.....	.....	4.861	4.991
+46	5.140	.....	.....	5.092	.....	.....	4.919	5.066
+50	.....	.....	.....	5.129	.....	.....	.....	5.111
+60	.....	.....	.....	5.221	.....	.....	.....	5.252
+70	.....	.....	.....	5.313	.....	.....	.....	5.428
+80	.....	.....	.....	.....	.....	.....	.....	5.665
+90	.....	.....	.....	.....	.....	.....	.....	5.986
+100	.....	.....	.....	.....	.....	.....	.....	6.433

known that the specific heat is increasing very rapidly with increasing temperature, it was imperative that the ammonia be heated only over small temperature ranges so that the mean value of the specific heat so determined, would be very closely the actual value of the specific heat at the mean temperature of the experiment. These two requirements, (1) a massive container, and, (2) heating over small temperature ranges, seriously affect the precision attainable with this method, though it is believed that it is the only one so far proposed which is adapted to measurements of the specific heat in the region under investigation.

Probably the principal source of error lies in the fact that the parts of the calorimetric apparatus do not change temperature at the same rate during the heating, and that considerable time must elapse after

the heating current is cut off before these temperature differences are equalized, which makes the equalized temperature at the time the switch is opened, difficult to determine.

Some time was devoted to an experimental study of the law of cooling of this calorimeter for temperature differences of 4° or 5° between the calorimeter and the bath, and these experiments showed, what is well known, that Newton's Law of Cooling is not exactly obeyed. The actual law was complicated and no simple expression was derived for it. The error made by the assumption of Newton's Law, is however, much smaller than the error made by the uncertainty in the final equalized temperature. Its use was therefore considered to be legitimate under these conditions. The assumption of linearity of the initial and final lines is theoretically unjustifiable, but practically, no error is made by using them as such. A very slightly higher value of R_2 and therefore a lower value of c_v would result from taking account of the curvature of the final line.

The values of k in Newton's Law of Cooling, varied from one measurement to another, which is accounted for by the fact that the environment of the calorimeter was not absolutely reproducible. In a vacuum-jacketed calorimeter, a major part of the heat transfer to the surroundings takes place through the cover; and in this apparatus, the stirring shaft and leads served to conduct a considerable quantity of heat from the cover directly to the room, which in most measurements was considerably below the temperature of the calorimeter, and furthermore, was not controllable as was the oil bath. The most accurate method, therefore, of dealing with the heat transfer, seemed to be: to compute k for each measurement from the differences of slope and temperature of the initial and final lines.

The constancy of the stirring energy input is hardly open to question, because during all the measurements, readings were taken at one minute intervals of the voltage drop across the armature of the stirring motor, and in no case did this voltage change enough to give a measurable change of slope in the temperature curve. This effect was separately investigated by changing the motor voltage and observing the effect on the temperature-time curve. A change of 10% in the stirring motor voltage was found to be necessary before the slope of the temperature curve was changed by a measurable amount. During the measurements the voltage variations were very much less than this.

As the measurements were being made and computed, it was realized that the accuracy attainable by this method was less than had been

hoped for, the average deviation of $\frac{\delta H_1}{\delta \theta}$ and $\frac{\delta H_2}{\delta \theta}$ from the curves taken to represent them, being of the order of 0.5%. No considerable amount of time was spent in checking these values, it being considered more profitable to spend the time improving the method so as to avoid the principal sources of error, and at the same time retain the essential idea, which is the measurement of the specific heat *at* a point.

These results are now published because there have hitherto been no data above 70° C., and the values of Drewes are not wholly reliable even to that temperature.

It is unfortunate that while these measurements of c_v extend to 125° C. or within 8° of the critical point, the values of c_{s_2} and c_{s_1}, can only be computed up to 100° C. owing to the lack of data on v_1 above that temperature.

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The writer is under great obligations to William H. Gran, and Frederick L. Brown for their careful and conscientious work in taking observations during the final measurements.

To Mr. F. Küng, Departmental Mechanician, is due the mechanical excellence of the apparatus. The writer owes much to his continued interest in the investigation.

Throughout the course of the investigation, Dr. George V. McCauley has offered many suggestions of great value, and to him the writer's best thanks are due for his very material assistance.

To Professor Henry Crew, under whose direction the work was carried on, the writer offers his sincere thanks for his advice and assistance, as well as for the generous manner in which the facilities of the laboratory have been placed at his disposal, and special apparatus and equipment purchased.

Acknowledgment is made of a generous grant from the Rumford Fund of the American Academy of Arts and Sciences, which made possible the purchase of the Calorimetric Wheatstone Bridge.

IX. Appendix.

1. Summary of Notation.

δH Any increment of energy added to the calorimetric system through the heating coil.

δH_1 An increment of energy added to the calorimetric system through the heating coil, container filled with ammonia.

δH_2 An increment of energy added to the calorimetric system through the heating coil, container empty.

$\delta\theta$ Change of temperature, on the Centigrade scale, of the calorimetric system due solely to the heat δH.

$\frac{\delta H}{\delta\theta}$ General expression for the heat capacity of the calorimetric system.

$\frac{\delta H_1}{\delta\theta}$ Heat capacity of the calorimetric system when the container is filled with ammonia.

$\frac{\delta H_2}{\delta\theta}$ Heat capacity of the calorimetric system when the container is empty.

δQ That portion of δH_1 absorbed by the ammonia.

$\frac{\delta Q}{\delta\theta}$ Heat capacity of the ammonia.

θ In general, temperature in ° C.; also used to denote the temperature of the observing thermometer at any instant.

θ_x Any particular temperature θ.

θ_a Temperature of the surroundings of the calorimeter.

θ_m Mean temperature during a calorimetric temperature change.

θ_p Platinum temperature defined by $\theta_p = \frac{100\ (R - R_{0°})}{R_{100°} - R_{0°}}$

$\frac{d\theta_r}{dt}$ Time rate of change of temperature in the calorimeter due solely to heat transfer to the surroundings.

$\frac{d\theta_s}{dt}$ Time rate of change of temperature in the calorimeter due solely to stirring.

T Absolute temperature on the Centigrade scale.

c Specific heat capacity.

c_{s_1} Saturation specific heat capacity of the vapor.

c_{s_2} Saturation specific heat capacity of the liquid.

c_v Specific heat capacity at constant specific volume.

$c_{v_{12}}$ Specific heat capacity at constant specific volume, of a mixture of liquid and vapor.

c_{v_a} Specific heat capacity at the constant specific volume a.

c_{v_b} Specific heat capacity at the constant specific volume b.

$c_{v_{2.6593}}$ Specific heat capacity at the constant specific volume 2.6593 ccs/gm.

v Specific volume.

v_1 Specific volume of saturated vapor.

v_2 Specific volume of saturated liquid.

v_{12} Specific volume of mixture of liquid and vapor.

v_a The particular specific volume a.
v_b The particular specific volume b.
$v_{2.6593}$ The particular specific volume 2.6593 ccs/gm.
V Total volume enclosed by the container.
E Average voltage drop across heating coil during a heating period.
I Average current through heating coil during a heating period.
M Total mass of ammonia in container.
M_1 Mass of ammonia vapor in container.
M_2 Mass of liquid ammonia in container.
p Pressure.
L Total heat of vaporization of the liquid.
K Modulus in Newton's Law of Cooling, using Centigrade scale.
k Modulus in Newton's Law of Cooling, using resistance scale.
R Resistance of thermometer at temperature θ.
R_k Constant in Keyes equation of state. (32)
R_0 Resistance of thermometer corresponding to the temperature at beginning of an initial line.
R_1 Resistance of thermometer corresponding to the temperature at end of an initial line.
R_2 Resistance of thermometer corresponding to the temperature at end of a heating period.
R_3 Resistance of thermometer corresponding to the temperature at end of a final line.
R_a Resistance of thermometer corresponding to θ_a.
R_m Resistance of thermometer corresponding to θ_m.
$R_{0°}$ Resistance of thermometer at 0 °C.
$R_{100°}$ Resistance of thermometer at 100 °C.
δR Change of resistance of thermometer corresponding to $\delta\theta$.
$\frac{dR_r}{dt}$ The equivalent on the resistance scale of $\frac{d\theta_r}{dt}$
$\frac{dR_s}{dt}$ The equivalent on the resistance scale of $\frac{d\theta_s}{dt}$
$\frac{dR_c}{dt}$ The equivalent on the resistance scale of $\left(\frac{d\theta_r}{dt} + \frac{d\theta_s}{dt}\right)$
t Time.
t_0 Time at beginning of an initial line.
t_1 Time at end of an initial line.
t_2 Time at end of a heating period.
t_3 Time at end of a final line.

λ A constant denoting the rate of temperature change due to stirring alone.
τ A parameter used in Equation 35.
δ Used as a symbol for an increment.
δ_c Constant in the Callendar-Griffith's equations (19) and (20).
δ_k A function in Keyes equation of state, (32).
a A constant in Keyes equation of state, (32).
l A constant in Keyes equation of state, (32).

ABSTRACT.

The specific heat-capacity at the constant specific volume 2.6593 ccm./gm. of a mixture of the liquid and vapor phases of ammonia (NH_3), has been determined in the temperature range 30° — 125° C. The method employed consists of transferring to a calorimeter measured amounts of electrical energy, each sufficient to raise the temperature of the system approximately one degree. These changes of temperature were measured by means of a platinum resistance thermometer. The heat capacity of the system was measured first when the apparatus was loaded with ammonia, and again when the apparatus was empty. At any particular temperature, the difference of these heat capacities is the heat capacity of the ammonia, and knowing the mass of ammonia present, the specific heat capacity is computed.

The calorimeter was a steel tube containing mercury, in which were immersed the ammonia container, a thermometer and a heating coil, the whole being jacketed in a Dewar vacuum flask, enclosed in a vessel and totally submerged in an oil bath whose temperature could be controlled. A special calorimetric Wheatstone Bridge was used in connection with the platinum resistance thermometer.

A special method of computing the calorimetric curves and the cooling correction was developed.

The experimental results consist of two curves, giving the heat capacities of the apparatus when loaded with ammonia, and when empty, as a function of the temperature. The values of the specific heat of the particular mixture of liquid and vapor mentioned above, are computed and the results given in Table II.

Equations are given which permit the computation of any other specific heat in the liquid-vapor region, or on the boundary of that region, from the experimentally determined values of the specific heat at constant specific volume.

Using the Keyes-Brownlee data for ammonia, the saturation specific heats of the liquid and vapor phases have been computed as far as 100° C. and these results are given in Table III.

The principal sources of error of this method are discussed.

NORTHWESTERN UNIVERSITY,
July 1919.